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Cactus pear management alternatives in Brazilian savannah: agronomic aspects, chemical composition, macro and micronutrient content

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Abstract. The cactus pear is a plant that can survive and produce under the soil and climatic conditions of tropical regions, but its management is still relatively little known in the Brazilian savannah. The objective of this study was to evaluate management alternatives for the cactus pear variety Doce, subjected to different cutting intensities, preserving the matrix, primary or secondary cladodes, and two harvest ages (annual and biennial), under rainfed conditions in the Brazilian savannah. A completely randomized design was adopted in a 3 × 2 factorial scheme, with eight replications. Morphometric and production variables, chemical composition, as well as macro and micronutrient contents were assessed. Greater amounts of green forage mass yield (GFMY) and dry forage mass yield (DFMY) were found when up to the primary cladode was preserved, but the crude protein content was like that found in the matrix cladode cutting intensity. Managing the cactus pear under biennial harvest provided higher height, GFMY, DFMY, potassium, and micronutrient accumulation. The management alternative that provides the most benefits in terms of agronomic characteristics and production is the one that preserves up to the primary cladode associated with biennial harvest. In addition, biennial harvest provides better chemical composition and greater accumulation of macro and micronutrients in cactus pear cultivar Doce.

Keywords: *cladode, cutting intensity, harvest, Nopalea cochenillifera*

Introduction

Cactus pear variety Miúda or Doce (*Nopalea cochenillifera*) is a cactus species that can survive and produce in the soil and climatic conditions of tropical regions, making it a favorable option to be used in animal feeding (Edvan *et al*., 2020). This species has the potential for high forage production, which contributes to the availability of feed, making it an interesting alternative for farmers (Silva *et al*., 2021). In addition, it increases feed security for herds during periods of scarcity (Miranda *et al*., 2019).

In *Nopalea cochenillifera*, agricultural and livestock use is directed primarily toward cladode biomass, which serves as forage and as a source of mucilage and other functional ingredients. Fruit production, in contrast, is not a major productive aim.

This context highlights the importance of prioritizing cladode yield and quality assessments in animal science and agronomic research (Dubeux Jr. *et al*., 2021).

In the arid regions of Brazil, cactus pear is widely used as animal feed (Araújo Jr *et al*., 2021). The variety Doce stands out for its adaptive traits. It has a high biomass yield, serving as excellent energy source rich in non-fiber carbohydrates and total digestible nutrients (Edvan *et al*., 2020). Furthermore, it has high levels of both macro and micronutrient (Carvalho *et al*., 2020), enhancing its suitability for animal nutrition, particularly during the dry season. The macronutrient and micronutrient composition of *Nopalea cochenillifera* cladodes underscores the crop's high value both as forage and as a source of functional biomolecules, thereby providing a compelling rationale for promoting its cultivation in semi-arid systems. Spineless cactus cladodes are characterized by high water and soluble carbohydrate content, along with low neutral detergent fiber. Additionally, they supply a range of macro elements (notably K, Ca, and Mg) and micronutrients that, when properly balanced in the diet, can meet the nutritional needs of ruminants (Pessoa *et al*., 2024).

Evaluating management alternatives through cutting intensity and harvesting age of this crop in the Brazilian savannah is important, since these are characteristics that confer productivity and influence the re-sprouting potential of cactus pear orchards and can change the chemical composition of cladodes (Nascimento *et al*., 2020), since there is little information for this region. When the cactus pear is cut, the unharvested primary cladodes tend to retain more water than the secondary cladodes, which means that their anatomical and morphological characteristics depend on the management (Teles *et al*., 2024). A greater number of preserved cladodes indicates a larger photosynthetic area, which can result in faster regrowth and increased productivity (Souza *et al*., 2020). Harvest age influences cladode sprouting and can modify growth, production, chemical composition, and macro and micronutrient content. Therefore, stimulates the production of this crop (Oliveira *et al*., 2021).

It is hypothesized that the cutting intensity preserving the primary cladode associated with the biennial harvest of cactus pear Doce will cause greater growth, higher production, better chemical composition, and greater accumulation of minerals. Thus, the objective of this study was to evaluate the agronomic characteristics, chemical composition, and macro and micronutrient content of cactus pear variety Doce in the Brazilian savannah region according to three cutting intensities and two harvest ages under rainfed conditions.

Material and Methods

Experimental area

The experiment was conducted at the campus of Professor Cinobelina Elvas (UFPI/CPCE) of the Federal University of Piauí, in the town of Bom Jesus, Piauí, Brazil, located at latitude 09º04'28" South, longitude 44º21'31" West, and at an altitude of 277m. According to the Köppen classification, the climate in the region is Aw (tropical hot and humid, with a dry season from spring to summer and a rainy season from fall to winter. The region's vegetation is Cerrado, which is equivalent to the Brazilian savannah (Costa-Coutinho *et al*., 2020). Data on rainfall, temperature and air relative humidity during the experimental period from 2020 to 2022 are shown in Figure 1.

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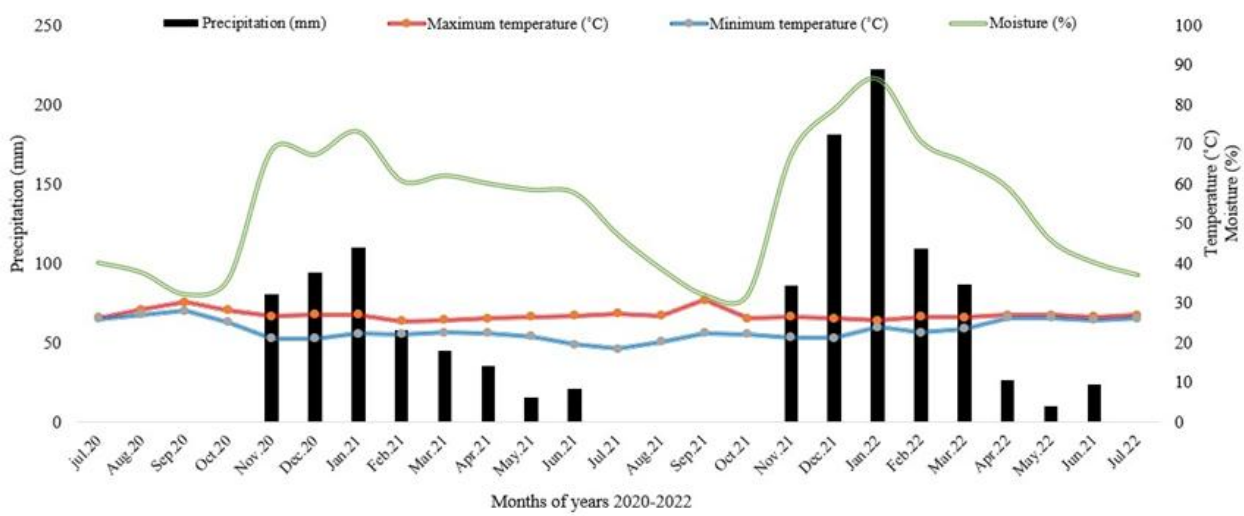

Figure 1. Accumulated monthly averages of rainfall, maximum and minimum temperatures, and air relative humidity during the experimental period in Bom Jesus, Piauí, Brazil.

Experimental design

The experimental design was completely randomized in a 3 × 2 factorial scheme, with eight replications. The first factor corresponded to three cutting intensities (preserving only the matrix cladode, up to the primary cladode, or up to the secondary cladode (Figure 2). The second factor consisted of two harvest ages (annual and biennial).

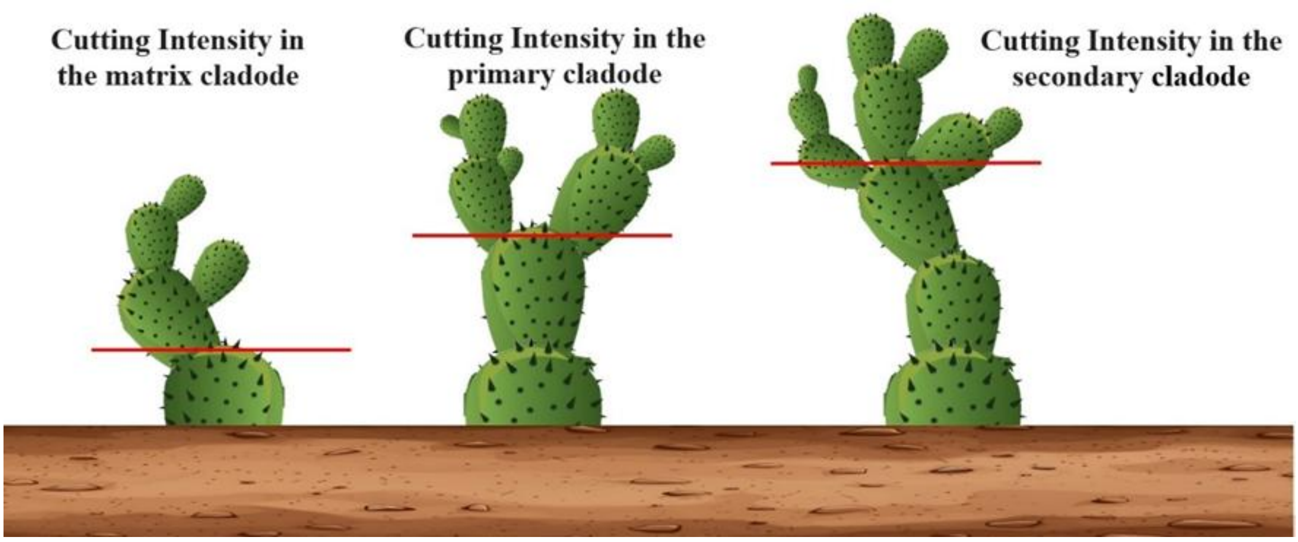

Figure 2. Cutting intensity of cactus pear variety Doce according to treatment, preserving the Matrix, Primary and Secondary cladodes.

Cactus pear cultivation

The cactus pear variety Doce (*Nopalea cochenillifera*) was planted in July 2020, in single row spacing (1.5 m × 0.1 m) corresponding to a density of 66,670 plants ha^{-1}, with 50% of the cladode buried in the soil, in an upright position. Each experimental unit (plot) contained 16 plants, with eight useful plants per plot, which were evaluated at the end of each year. The selection of the eight plants evaluated in each plot was carried out through random sampling, excluding plants located on the border of the plot. The experiment was conducted under rainfed conditions. The evaluation period lasted two years, with two cutting cycles depending on the treatment (annual harvest in July 2021 and July 2022, and biennial harvest in July 2022).

Manual weeding was performed to control weeds. Regarding integrated pest management (IPM), a 1% mineral oil solution (200 mL of product per 20 liters of water) was applied to control the scale insect (*Diaspis echinocacti*), and thiacloprid was used to control the carmine cochineal (*Dactylopius opuntiae*) when present on some plants. Only one application was made annually using personal protective equipment (PPE) (Santos et al., 2002). Fertilization was carried out at the moment of sowing in July 2020 (sowing fertilization), and in July 2021 (maintenance fertilization), following the recommendations of Edvan and Carneiro (2019), with application at sowing of 45 kg of phosphorus ha^{-1} (single superphosphate, 18% P_2O_5), 80 kg of potassium ha^{-1} (potassium chloride, 60% KCl), and 100 kg of nitrogen ha^{-1} (urea, 45% N).

Evaluation of growth and production

Two harvests were made to evaluate the cactus pear. The annual harvest occurred in July 2021 and July 2022, while the biennial harvest occurred in July 2022 at the recommended cutting intensities. Plant morphometric characteristics were assessed before each harvest, and then production characteristics were evaluated according to the treatments, excluding border plants.

The morphometric variables assessed were plant height (cm), number of cladodes per plant, as well as length and width of cladodes per plant (cm). To quantify the height and width of the plant, a tape measure graduated in cm was used, measuring vertically from the base of the plant to the highest point (height) and horizontally, from one point to another on the plant with the largest wingspan (width). The number of cladodes was obtained by counting them. Cladode area (CA) was determined as described by Cortázar and Nobel (1991) using the following equation: $CA = Length \times Width \times 0.632$. For the production evaluations, cladodes from all plants were harvested at the end of the annual and biennial evaluations, across all cutting intensities and harvesting ages evaluated.

Considering the factor cutting intensity, the matrix, primary or secondary cladodes were preserved, while the forage masses above these cladodes were harvested by cutting at the intersection of the cladodes. The weights of all cladodes harvested were determined in the field using a weighing scale with a precision of 1g. The green forage mass yield (GFMY) of cactus pear was determined at harvest, in Mg ha^{-1}. Subsequently, the samples were taken to the laboratory, where the dry forage mass yield (DFMY) was determined. The harvesting age factor consisted of the sum of harvests carried out in 2021 and 2022 for the variables GFMY and DFMY, respectively.

Chemical composition analysis

Chemical analyses were carried out by determining the fractions of neutral detergent fiber (NDF) and acid detergent fiber (ADF), obtained from the methodology described by Mertens *et al*. (2002), adapted for autoclave equipment (105 °C, 60 min) according to Barbosa *et al*. (2015), who used 4×5cm-non-woven fabric bags (TNT, 100 g m^{-2}) with porosity of 100 µm (Valente *et al*., 2011). The contents of dry matter (DM) at 105 ºC, crude protein (CP) (method 988.05) and mineral matter (MM, method no. 942.05) were determined according to AOAC (1998) procedures.

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Determination of macro and micronutrient contents

Macro and micronutrients were determined using the nitric-perchloric digestion method. The phosphorus (P) content was determined by UV/VIS spectrophotometry at 660 nm by reading the intensity of the blue color of the phosphomolybdic complex produced by the reduction of molybdate with ascorbic acid in an IL-592 EVEN® spectrophotometer. The contents of Calcium (Ca), magnesium (Mg), potassium (K), copper (Cu), manganese (Mn), iron (Fe) and zinc (Zn) were determined by atomic absorption spectrophotometry (AAS), in a spectrophotometer model AA240FS VARIAN®, according to the methodologies described by Silva (2009), and carried out at the CPCE/UFPI Soil Analysis Center.

Statistical analysis

Data were analyzed using a completely randomized design, in a factorial arrangement with cutting intensities and two harvest ages (3 × 2) in eight replications, according to the following mathematical model adopted in Equation 1:

$$y_{ij} = \mu + t_i + b_j + (t \times b)_{ij} + e_{ij} \quad [1]$$

where: y_{ij} = observed value in the plot of the i^{th} factor 1 in the j^{th} factor 2; μ = experimental mean; t_i = effect of the i^{th} factor 1 in the experimental plot; b_j = effect of the j^{th} factor 2 in the experimental plot; $(t \times b)_{ij}$ = effect of interaction between factor 1 and factor 2; e_{ij} = uncontrolled random error in the plot of the i^{th} factor 1 in the j^{th} factor 2.

Data was subjected to analysis of variance and interaction of factors at a significance level of $p < 0.05$. Tukey's test was used for the analysis of cutting intensity and harvesting age. All analyses were conducted with a significant level of $p<0.05$. The SISVAR software version 5.0 (Ferreira, 2011) was used for the analyses.

Results

No effect of interaction ($p>0.05$) between cutting intensity and harvest age was observed on any of the agronomic and production characteristics evaluated. On the other hand, there was an effect ($p=0.04$) of cutting intensity and harvest age on plant height and GFMY, and an effect ($p=0.01$) of cutting intensity on DFMY. The management strategy that preserves only the matrix cladode showed lower plant height, GFMY and DFMY when compared to the management that preserved up to the primary cladode (Table 1). It should also be noted that GFMY and plant height were lower when the harvest was annual. On the other hand, it is important to note that the DFMY values were similar across the evaluated harvest ages. Regarding the chemical composition, DM and MM contents were affected by the interaction of factors ($p<0.01$) (Table 2), while the CP content was affected only by the cutting intensity ($p=0.032$). It was also observed that higher DM content was associated with the secondary cladode when up to the primary cladode was preserved, while the MM content was lower when up to the secondary cladode was kept, associated with the annual harvest age, and up to the secondary cladode associated with the biennial harvest age. As for the CP content, the highest value was observed when keeping up with the secondary cladode (Table 2).

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Table 1. Agronomic and production characteristics of cactus pear subjected to different cutting intensities and harvest ages.

Variables	**Cutting intensity (CI)**				
	Matrix	**Primary**	**Secondary**	***p*-value**	**SEM**
Number of cladodes	8.13a	7.56a	9.31a	0.4960	0.86
Cladode area (cm²)	77.13a	84.88a	82.46a	0.5169	4.83
Plant height (cm)	61.06b	72.94a	70.56a	0.0034	2.43
GFMY[1] (Mg ha^{-1})	64.39b	111.26a	85.21ab	0.0455	12.77
DFMY[2] (Mg ha^{-1})	5.68b	10.66a	7.73ab	0.0139	3.93
	Harvest age (HA)				***p*-value**
	Annual	**Biennial**	***p*-value**	**SEM**	**CI × HA**
Number of cladodes	7.46a	9.21a	0.1602	1.05	0.6315
Cladode area (cm²)	79.89a	83.10a	0.5692	3.94	0.5216
Plant height (cm)	63.46b	72.92a	0.0018	1.98	0.2212
GFMY[1] (Mg ha^{-1})	65.56b	108.45a	0.0064	10.43	0.7927
DFMY[2] (Mg ha^{-1})	6.78a	9.26a	0.0677	0.93	0.8042

[1]GFMY: total green forage mass yield. [2]DFMY: total dry forage mass yield. [3]SEM: standard error of the mean. Means followed by the same letter in the row do not differ from each other according to the Tukey's test at p<0.05.

Table 2. Chemical composition of cactus pear Doce subjected to different cutting intensities and harvest ages.

Harvest age (HA)	**Cutting intensity (CI)**				***p*-value**			
	Matrix	**Primary**	**Secondary**	**Mean**	**CI**	**HA**	**CI × HA**	**SEM[1]**
	Dry matter (DM g kg^{-1})							
Annual	84.8bB	84.4bA	89.9aA	86.4	0.003	0.001	0.001	0.2
Biennial	86.3bA	83.6cB	87.7aB	85.9				
Mean	85.6	84.0	88.8					
	Crude protein (CP. g kg^{-1} DM)							
Annual	62.5	56.2	61.2	60.0	0.032	0.214	0.066	0.7
Biennial	50.7	52.3	66.5	56.5				
Mean	56.6ab	54.2b	63.8a					
	Neutral Detergent Fiber (NDF. g kg^{-1} DM)							
Annual	293.7	290.5	282.2	288.8	0.252	0.114	0.562	10.2
Biennial	291.7	260.5	252.8	268.3				
Mean	292.7	275.5	267.5					
	Acid Detergent Fiber (ADF. g kg^{-1} DM)							
Annual	171.1	169.2	181.9	174.1	0.954	0.305	0.449	9.4
Biennial	165.3	171.2	150.4	162.3				
Mean	168.2	170.2	166.1					
	Mineral Matter (MM g kg^{-1} DM)							
Annual	33.6aA	30.2aB	44.2aA	36.0	0.010	0.012	0.009	5.5
Biennial	51.0aA	55.0aA	27.5bA	44.5				
Mean	42.3	42.6	35.8					

[1]SEM: standard error of the mean. Lowercase letters compare means in the row and uppercase letters compare means in the column according to the Tukey's test at p<0.05.

There was a significant effect of interaction (*p*<0.01) between harvesting age and cutting intensity on the contents of Ca, Mg, and P, but not on the K content (Table 3). Higher Ca contents were reported when up to the primary or only the matrix cladodes were preserved in comparison to keeping up to the secondary cladode associated with annual harvest. However, the Ca content was higher when the secondary cladode was preserved up to the biennial harvest.

Table 3. Macronutrient accumulation in cactus pear subjected to different cutting intensities and harvest ages.

Harvest age (HA)	**Cutting intensity (CI)**				***p*-value**			
	Matrix	**Primary**	**Secondary**	**Mean**	**CI**	**HA**	**CI × HA**	**[1]SEM**
	Calcium (Ca, g kg^{-1})							
Annual	25.62aA	22.89aB	19.06bB	22.52	0.002	0.001	0.001	0.91
Biennial	19.20cB	30.78bA	34.52aA	28.179				
Mean	22.41	26.84	26.78					
	Magnesium (Mg. g kg^{-1})							
Annual	8.84aA	9.56aA	7.26bB	8.55	0.004	0.001	0.001	0.24
Biennial	8.89cA	10.30bA	11.51aA	10.23				
Mean	8.86	9.93	9.38					
	Phosphorus (P. g kg^{-1})							
Annual	0.64aB	0.50aB	0.46aB	0.53	0.001	0.001	0.001	0.05
Biennial	1.59aA	1.47aA	0.84bA	1.30				
Mean	1.12	0.98	0.65					
	Potassium (K. g kg^{-1})							
Annual	44.6	96.0	50.7	63.8B	0.016	0.028	0.208	0.74
Biennial	72.9	95.4	89.0	85.7A				
Mean	58.7b	95.7a	69.9ab					

[1]SEM: standard error of the mean. Lowercase letters compare means in the row and uppercase letters compare means in the column according to the Tukey's test at *p*<0.05.

Magnesium values were lower when keeping up to the secondary cladode associated with the annual harvest. Also, the lowest P values were observed when the plants were harvested annually, regardless of the cutting intensity. The highest concentration of K was observed under the primary cladode cutting intensity associated with biennial harvest (Table 3).

No effect of interaction (*p*>0.05) between harvest age and cutting intensity was observed on Cu, Mn, Fe, and Zn contents (Table 4). There was only a difference in the Mn content of cactus pear according to the cutting intensities. Regarding the harvest age, Cu, Mn, Fe, and Zn contents were higher when the cactus pear was harvested biennially.

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Table 4. Micronutrient accumulation in cactus pear subjected to different cutting intensities and harvest ages.

Variables	Cutting intensity (CI)				
	Matrix	Primary	Secondary	*p*-value	[1]SEM
Copper (Cu, mg kg^{-1})	7.86a	8.84a	8.48a	0.9416	2.03
Manganese (Mn, mg kg^{-1})	66.74a	52.79b	55.85ab	0.0350	3.36
Iron (Fe, mg kg^{-1})	235.56a	216.17a	285.94a	0.8027	75.98
Zinc (Zn, mg kg^{-1})	45.09a	50.99a	38.89a	0.2335	4.66
	Harvest age (HA)				*p*-value
	Annual	Biennial	*p*-value	SEM	CI × HA
Copper (Cu, mg kg^{-1})	3.81b	12.98a	0.0029	1.66	0.3469
Manganese (Mn, mg kg^{-1})	50.74b	66.18a	0.0026	2.74	0.0507
Iron (Fe, mg kg^{-1})	120.03b	371.75a	0.0167	62.04	0.7121
Zinc (Zn, mg kg^{-1})	38.23b	51.75a	0.0307	3.80	0.0515

[1]SEM: standard error of the mean. Lowercase letters compare means in the row and uppercase letters compare means in the column according to the Tukey's test at $p<0.05$.

Discussion

Production and agronomic characteristics

Regarding the cutting intensity with preservation of the primary cladode, associated with the biennial harvest of the cactus pear Doce, there was greater growth and production, confirming the hypothesis for these variables. It is emphasized that preserving the primary cladode during harvest serves as a key management strategy to maintain the plant's photosynthetic capacity and carbohydrate reserves, thereby promoting bud reinitiation and accelerating vegetative regeneration. The preserved primary cladodes function as a continuous source of assimilates and active meristems, reducing the stress associated with the complete removal of the aerial portion and enabling the formation of a greater number of secondary shoots, as well as increased biomass accumulation throughout the regrowth cycle (Gomes *et al*., 2024).

This effect physiologically explains the enhanced growth and yield observed when this cutting intensity is combined with biennial harvesting. However, the chemical composition and macro and micronutrient contents were more influenced by the biennial harvest age.

The area and number of cladodes were not influenced by harvest age or cutting intensity. However, the height of the plant was lower when only the matrix cladode was preserved. Plants managed at a higher initial height (primary and secondary cladodes) have higher heights when compared to those managed at a lower initial height (matrix cladode) (Marques *et al*., 2017). Higher plant height was also observed at the biennial harvest age. This can be explained by the longer time interval for harvest, which allowed for greater growth (Jardim *et al*., 2023).

It is observed that the management strategy of preserving up to the primary cladode was more beneficial, as it resulted in greater GFMY and DFMY (Pereira *et al*., 2020). Unharvested secondary cladodes have larger cladode area that requires more organic reserves to maintain during the dry season, and this increase in energy expenditure affects the speed of regrowth and compromises DFMY (Lima *et al*., 2016; Araújo Júnior *et al*., 2021). Dry forage mass yield was higher when the

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strategy of preserving up to the primary cladode were adopted (Table 1), allowing the maintenance of plant water status, greater supply of organic reserves, and, probably, increase in the cladode thickness, which contributed to the greater accumulation of dry matter (Lima *et al*., 2016; Pereira *et al*., 2020).

Therefore, it is important to adopt the management that preserves up to the primary cladode, as they have greater availability of photosynthetic surface, water and organic reserves, distributing nutrients and water to the other cladodes, and is the main responsible for supporting the plant (Queiroz *et al*., 2015; Araújo Júnior *et al*., 2021; Jardim *et al*., 2023).

Cactaceae are CAM-type plants and exhibit slow growth, making it important to adopt the longest possible experimental period. An experimental duration that allows for two biennial cuts of the forage cactus can permit better exploration of the GFMY and DFMY variables, yielding more consistent results regarding the optimal harvest time (annual or biennial) and the optimal cutting intensity (preserving primary cladodes or preserving secondary cladodes).

Chemical composition

Regarding the cutting intensity, the DM content was higher when up to the secondary cladode was preserved at both harvest ages (Table 2). While regarding the harvest age, the greatest DM contents were observed in the biennial harvest when only the matrix cladode was preserved and in the annual harvest when up to the primary or secondary cladodes were preserved, respectively. The higher DM content of cactus pear Doce when up to the secondary cladode was preserved in the annual harvest was probably due to the greater accumulation of cell wall over the years in the matrix, primary and secondary cladodes. Due to the continuous growth and consequent increase in the fiber portion and lignin, the matrix cladode ages and strengthens to support the generation of new cladodes, which increases the plant's DM content (Da Silva *et al*., 2012). The chemical composition of the plant tends to be more strongly influenced by the age of the tissue at harvest than by cutting intensity itself. Younger and older cladodes exhibit marked differences in water content, dry matter, proportions of soluble carbohydrates, fiber, and mineral concentrations. Therefore, even in systems managed to enhance productivity (such as the preservation of the primary cladode combined with biennial harvesting), the nutritional composition of the cladodes remains strongly determined by their physiological age at the time of harvest.

However, in contrast to the DM content, it should be noted the high average water content in the cactus pear of around 910 g kg^{-1}. The water present in the cactus pear cladodes is one of the main benefits of this feed in semi-arid regions, since this natural resource is one of the main limiting factors for animal production (Ramos *et al*., 2011). In regions exposed to high temperatures and prolonged periods without rainfall, as observed in this study (Figure 1), the usefulness of cactus pear is reinforced by its morphophysiological adaptations that enable the maintenance of elevated water levels in its cladodes. These cladodes function as water reservoirs, providing the plant with resilience to both water and thermal stress. Notably, this species exhibits a remarkable capacity to store water within its tissues, allowing the cladodes to act as buffers against dehydration even under extended heat exposure (Cony *et al*., 2008).

The higher CP contents in the cutting intensity that preserves up to the secondary cladode may be related to the presence of lower cell content in this cladode, which has a greater fiber fraction and

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lignin to support the plant (Cavalcante *et al*., 2014). Considering that catus pear is known to present low CP content, on average 50 g kg^{-1}, harvesting younger cladodes, which favor a greater accumulation of this nutrient, can be beneficial for animal feeding (Cavalcante *et al*., 2014; Marques *et al*., 2017).

The NDF and ADF contents found in the cactus pear Doce were like those found in the literature (Bezerra *et al*., 2023), regardless of the cutting intensity and harvest age. Although it is considered a roughage, cactus pear has low levels of fiber carbohydrates (Gomes *et al*., 2018), and this aspect should be considered when using it in ruminant diets as a sole feed, as it can cause metabolic disorders in the animals and should be associated with other sources of fiber and nutrients to provide promising results (Cordova-Torres *et al*., 2015; Gomes *et al*., 2018).

Regarding the MM content, the high values observed in management strategies that preserved only the matrix or up to the primary cladodes in both annual and biennial harvests may be related to the concentration effect of this nutrient due to water loss and increasing plant age over the course of cultivation. According to Ferreira *et al*. (2006), cactus pear can show differences in MM content, which can be related to several factors, including the age of the cladodes, time of year, management applied, as well as soil and climate conditions of the cultivation site, and regardless of the genotype used, it shows high MM values.

Contents of macro and micronutrient

The highest accumulation of Ca (34.52 g kg^{-1}) and Mg (11.51 g kg^{-1}) occurred when the cutting intensity was preserved up to the secondary cladode associated with the biennial harvest (Table 3). According to Dubeux Júnior *et al*. (2022), the cactus pear has high levels of Ca and can provide the accumulation of this mineral in the form of oxalate. Calcium acts to maintain the structural and physiological stability of cladode tissues, regulates cell permeability processes, and serves as an enzyme activator (Taiz *et al*., 2017). Magnesium is part of the constitution of chlorophyll and plays a role in the photosynthetic process, as well as in other physiological processes and plant nutrition (Taiz *et al*., 2017). The Ca and Mg accumulated in the cactus pear in this study are in line with the levels found by Lima *et al*. (2023). Due to the important role, they play in the growth and development of cactus pear, macro and micronutrient are fundamental for this crop.

The highest K content was found in the treatments that preserved up to the primary cladode and were associated with biennial harvest. K is the macronutrient with high accumulation in cactus pear cladodes (Wakeel, 2013), and is essential for plant development, as it is involved in the processes of stomatal opening, photosynthesis, osmotic regulation, electrochemical balance, as well as being a cofactor for enzymatic activities, protein synthesis and stress signaling (Shabala and Pottosin, 2014).

The biennial harvest age favored the accumulation of P in the matrix, primary and secondary cladodes. Silva *et al*. (2012) also observed that cactus pear harvested at 620 days accumulated more P in the cladodes in comparison to the plants harvested at 390 days. Lower Mn content was observed in the cutting intensity that preserved up to the primary cladode where there was greater GFMY and DFMY, which extract more Mn from the soil. Silva *et al*. (2016) reported that Mn is the most demanded micronutrient by the cactus pear, probably due to its role in the oxidation-reduction process, which is essential for photosynthesis. Cactus pear accumulated more micronutrients at the biennial harvest

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age, and this accumulation of micronutrients is in line with Carvalho *et al*. (2020) but was higher than the values obtained by Ferraz *et al*. (2020).

Conclusion

The management alternative that provides the most benefits in terms of agronomic characteristics and cactus pear production consists of a cutting intensity that preserves the primary cladode, associated with biennial harvesting. The biennial harvest age yields a better chemical composition and greater accumulation of macro and micronutrients in the cactus pear variety Doce. Cactus pear allows for a long harvest period without significantly compromising its dry forage yield and chemical composition. Depending on the producer's needs, cactus pear allows for different management strategies to be adopted. For example, in years with low feed availability, harvesting can be annual to meet the animals' needs. On the other hand, in years with excess feed, the producer can choose not to harvest the cactus pear, preserving it for the following year.

ETHICS STATEMENT

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF SUPPORTING DATA

Supporting data will be provided by corresponding author upon reasonable request.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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AUTHOR CONTRIBUTIONS

RLE and AFP planned the experiment and performed the statistical analyses. DMAB carried out the field experiment. JPMP, SBL, LVS, GKSMV, SFS, MCM and CBMSX performed the chemical analyses and wrote the article. MLRS, LVS, FNPF and LFRC they brought the article into line with the journal's standards and reviewed the written work.

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