BIOSCIENCE JOURNAL

MORPHOMETRY AND BROMATOLOGY OF FORAGE CACTUS UNDER IRRIGATION FREQUENCIES IN A SEMI-ARID ENVIRONMENT

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How to cite: MIRANDA, J.R., et al. Morphometry and bromatology of forage cactus under irrigation frequencies in a semi-arid environment. *Bioscience Journal*. 2026, **42**, e42001. https://doi.org/10.14393/BJ-v42n0a2026-66781

Abstract
This study evaluated the morphometry and bromatology of the forage cactus cultivar *Opuntia stricta* (Haw.) Haw., which was drip-irrigated every 7 and 28 days in a semi-arid environment. The experiment was conducted under field conditions at the National Institute of the Semi-arid Region (INSA), Campina Grande, PB, Brazil. The experiment was conducted in a randomized block design, arranged in a 2 x 12 factorial scheme, with two irrigation frequencies (7 and 28 days) and 12 evaluation periods, resulting in 24 treatments distributed across four blocks over 12 months. Regrowth was conducted under a 2 x 5 arrangement, with two irrigation frequencies and five evaluation periods. The morphometric and bromatological characteristics of the forage cactus were evaluated 12 months after planting, and the morphometric characteristics 5 months after regrowth. The data were evaluated using analysis of variance, and the means were compared using Tukey’s test and the t-test at a 5% probability level, in SAS® (2002). The frequency of irrigation of 7 days yielded better morphometric and bromatological responses in the forage cactus. Irrigation at a low frequency and low water volume provides satisfactory forage cactus yields in a semi-arid environment.

Keywords: Cactus. Crude protein. Drip. Forage. *Opuntia stricta (Haw.) Haw*.

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Received: 28 August 2024
Accepted: 18 November 2025
Published: 08 January 2026

1. Introduction

The Brazilian semi-arid region is characterized by low and irregular rainfall, as well as high temperatures (Rodriguez et al. 2015; Bacalhau et al. 2017). Productive and economic losses are prevented through the cultivation of forage species adapted to the region, such as forage cactus, which have anatomical, physiological, and chemical characteristics that allow their growth and development in areas with high temperatures and water scarcity (Souza et al. 2018; Nogueira de Sá et al. 2021).

The forage cactus is an important feed resource for livestock in arid and semi-arid regions, accounting for up to 80% of ruminant diets due to its high energy and water content, as well as its high productivity per unit area. However, its inclusion in animal diets should be limited and complemented with other sources of fiber and protein, as excessive amounts reduce the diet’s neutral detergent fiber (NDF) content, provide low levels of fiber and protein, and contain high moisture in the mucilage, which may cause diarrhea in animals (Monteiro et al. 2014; Felix et al. 2016; Marques et al. 2017; Alves et al. 2017; Oliveira et al. 2018).

The bromatological composition and morphometric characteristics of the forage cactus are influenced by climate variables that can impact photosynthesis and other physiological and biochemical processes in plants, soil fertility, plant age, time of year, species, variety, sowing density, and pest and disease attacks (Silva et al. 2016; Souza et al. 2018). However, in the attempt to increase productivity, crops have been fertilized and irrigated, as the low volume of water may alter plant growth dynamics compared to forage cactus cultivated under rainfed conditions, increasing yield, quality, and productivity (Consolli et al. 2013; Silva et al. 2014; Queiroz et al. 2015; Lima et al. 2016; Cruz Neto et al. 2017; Marques et al. 2017; Rocha et al. 2017).

Irrigation frequency influences the emergence of primary, secondary, and tertiary cladodes (Silva et al. 2015; Rocha et al. 2017; Silva et al. 2019; Nunes et al. 2019), as water restriction may reduce the relative water content and the thickness and growth of cladodes (Scalisi et al. 2016; Nunes et al. 2020). Morphometry and chemical composition may vary between irrigated and rainfed forage cactus cladodes; hence, evaluating the morphometric characteristics and bromatology of cladodes in sequence is essential to make nutritional recommendations at harvest periods and understand their attributes as a feed source for livestock in the semi-arid region (Almeida 2012; Alves et al. 2017).

Thus, this study evaluated the morphometry and bromatology of the forage cactus cultivar *Opuntia stricta* (Haw.) Haw., which was drip-irrigated every 7 and 28 days in a semi-arid environment.

2. Material and Methods

The experiment was conducted at the Experimental Farm of the National Institute of the Semi-arid Region (INSA) in Campina Grande, PB, Brazil, at south latitude 07° 14' 00'', west longitude 35° 57' 00'', and altitude of 491 m. The region’s climate is classified as As, according to the Koppen classification (Francisco et al. 2015). The experimental period lasted 17 months, comprising the first year of the forage cactus cycle (January to December 2020) and the first five months of the second year (regrowth) (January to May 2021).

The soil of the experimental area is classified as Eutrophic Haplic Planosol with a sandy-loam texture, an average porosity of 50%, and a particle size of 82.16% sand, 16.08% silt, and 1.76% clay, according to the EMBRAPA methodology (2013). Soil preparation included plowing, harrowing, soil analysis, and fertilization with 200 kg of urea, 40 kg of monoammonium phosphate (MaP), and 60 kg of granular potassium chloride distributed homogeneously. The water used in the experiment was classified as C1S1, according to the analyzed characteristics, corresponding to low-salinity water.

The study obtained cladodes of the forage cactus cultivar *Opuntia stricta* (Haw.) Haw. from INSA, which were free from pest and disease infestations. Planting was conducted using field-cut cladodes, placed in furrows with a bilateral alignment (domino system).

The experiment had a randomized block design in a factorial scheme, with four replications. The treatments consisted of two irrigation frequencies (I7 - irrigation every 7 days; I28 - irrigation every 28 days), 12 evaluation periods in the first cycle (January through December), and five assessment periods for regrowth (January through May).

The planted area was 57.6 m², and the total area was 945 m² (18.9 m x 50 m) (Figure 1). The planted area comprised 432 plants, of which 216 were irrigated every 7 days in 28.8 m^2, as well as those irrigated every 28 days, with a planting density of 19,047 per hectare.

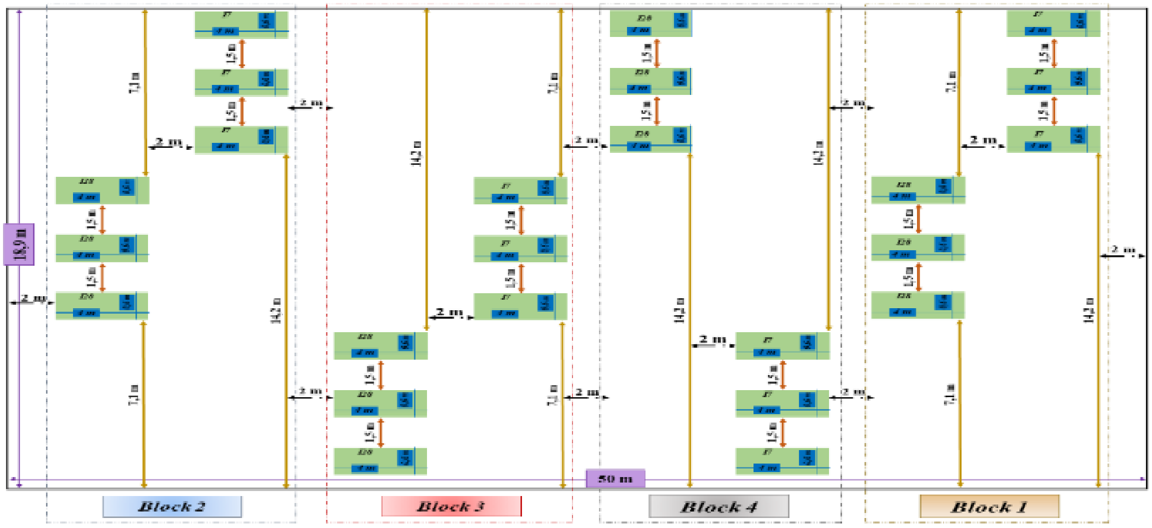

Figure 1. Total distribution of experimental blocks.
I7 - Irrigated every 7 days; I28 - Irrigated every 28 days.

Each experimental plot consisted of a double plant row with 18 plants (nine per row) and a planted area of 2.4 m². The row spacing was 0.6 and 0.5 m between plants, and the plot measured 4 m in length, 0.75 m in lateral borders, and 1 m in upper and lower borders. The total area per experimental plot, including the borders, was 12.6 m².

The experiment was conducted using a drip irrigation system, with GA 4-type drippers distributed in rows close to the plants, every 0.5 m. The hose, which was used as a pipe, had an internal diameter of 17 mm.

Irrigations were always performed in the afternoon, between 3 p.m. and 4:30 p.m. Plants irrigated at 7- and 28-day intervals received a fixed depth of 8.74 mm, applied to complement rainfall. The 7-day interval represented weekly irrigations, while the 28-day interval corresponded to irrigations every four weeks.

During the first cultivation cycle and regrowth, climatic variables such as temperature, relative humidity, insolation, and precipitation of the experimental area were evaluated using data from the automatic meteorological station of the National Institute of Meteorology (INMET) of the Brazilian federal government, located at Embrapa Cotton in Campina Grande, about 11 km from the experimental area.

The non-destructive (uncut) green matter biomass estimation was quantified during the first cycle and on the regrowth of the forage cactus cultivar *Opuntia stricta* (Haw.) Haw., in grams per plant, using the methodology by Menezes et al. (2005). The estimated average mass of cladodes was based on Equation (1).

$$CGMB = L * W * T * 0.535 \quad (1)$$

Where: CGMB - cladode green matter biomass in g;
L - Average length of cladodes in cm;
W - Average width of cladodes in cm;
T - Average thickness of cladodes in cm;
0.535 - Factor obtained by multiplying the area correction factor (0.883) by the corrected specific weight (0.772 g cm^{-3}), the value of 3.14, and ¼ of the ellipse area calculation, in g cm^{-3}.

Twelve months after planting (first cycle), the plants were cut (in December), and the primary, secondary, and tertiary cladodes of four plants were weighed in the field in each experimental plot at 7 and 28 days, using 48 plants for each treatment. Then, the cladode weights were added to obtain the weight of each plant and the partial field weight of the irrigated plants. Later, the total experimental field weight of the 432 plants was calculated, with 216 plants being irrigated every 7 and 28 days.

Morphometric analyses were conducted during the first cycle and on the regrowth of the forage cactus on four plants of each experimental plot. They evaluated the monthly vegetative growth of the morphometric variables for height (cm), width (cm), and thickness (cm) of the mother, primary, secondary, and tertiary cladodes. These variables were determined using a measuring tape and a digital caliper, measuring from the ground to the highest end of the plant. The number of primary, secondary, and tertiary cladodes was obtained through direct counting.

At the time of cutting (destructive analysis of the first cultivation cycle; 12 months after planting), a sample of primary, secondary, and tertiary cladodes was taken from each experimental plot. These samples were later homogenized within the block, and a composite sample was collected for each cladode order, totaling six samples per block (primary, secondary, and tertiary cladodes at irrigation frequencies of 7 and 28 days), enabling the bromatological analysis of individual cladodes.

The samples were dried in a circulation and air-renewal oven at 65°C for 72 hours, then ground in a Willey knife mill equipped with a 1mm sieve, and 0.600 g were placed in identified plastic bags. Dry matter (DM) and crude protein (CP) were determined in a nitrogen distiller (Kjeldahl method), ether extract (EE) in a Goldfish apparatus, mineral matter (MM) in an electric muffle at 600°C, and neutral detergent fiber (NDF) and acid detergent fiber (ADF) in an ANKOM fiber tester. The analytical methods from the Association of Official Analytical Chemists (AOAC, 1990) were used to determine the contents of DM (method #930.15), ash (method #942.05), crude protein (method #984.13), neutral detergent fiber, acid detergent fiber, and lignin, as per Van Soest et al. (1991). Total carbohydrates (TC) were calculated using the formula: TC (%DM) = 100 - (%CP + %EE + %RM). The data on morphometric variables were evaluated using analysis of variance (ANOVA), and the means were compared using Tukey's test at a 5% probability level. The collected bromatological data were evaluated using analysis of variance (ANOVA), and the means were compared using the t-test at 5% probability, applying the general linear model (GLM) procedure of SAS® (2002).

3. Results

The air temperature (AT, °C) in the first cycle was the highest in February (Table 3) and the lowest in July. During regrowth, the AT was the highest in February and the lowest in May. However, it remained within the appropriate range for cactus forage (18-32°C) in both periods (Bezerra et al. 2014). The average relative humidity (RH, %) in the first cycle was the highest in June and the lowest in January, remaining above the appropriate range for this forage, which should be 37.3 to 63.1% (Souza et al. 2008). During regrowth, RH was the highest in April and the lowest in February (Table 1).

Table 1. Meteorological data from the first cycle and the regrowth of the forage cactus.

Evaluation period	AT (°C)	RH (%)	WS (m s^{-1})	I (h)	P (mm)
First cycle					
January	25.70	72.38	3.47	7.10	16.00
February	26.13	73.92	3.39	8.50	5.80
March	25.51	79.71	2.44	7.10	173.40
April	24.99	81.73	2.54	7.40	97.20
May	24.27	83.46	2.67	7.00	65.60
June	22.62	84.98	2.49	5.10	84.90
July	21.68	82.33	2.44	7.05	73.10
August	22.28	75.33	3.13	8.50	8.70
September	22.77	74.98	3.49	8.05	10.80
October	24.26	72.88	3.82	9.30	0.80
November	24.92	74.94	4.09	8.50	13.60
December	24.64	74.54	4.21	8.30	1.30
Regrowth					
January	25.03	74.54	3.91	7.00	7.00
February	25.44	73.52	3.68	7.25	7.25
March	24.95	77.92	3.31	7.40	7.40
April	24.42	84.00	3.09	7.35	7.35
May	23.33	83.13	2.61	5.70	5.70

Source: Brazilian National Institute of Meteorology - Inmet.
AT (°C) – Average air temperature; RH (%) - Average relative humidity; WS (m s^{-1}) - Wind speed; I (h) - Insolation; P (mm) - Precipitation.

The wind speed (WS, m s^{-1}) in the first cycle was within the ideal range for forage cactus production from March to July - between 1 and 3 m s^{-1} (Silva et al. 2020), but it peaked in December. During regrowth, WS was within the ideal range for forage cactus only in May, and from January to April, it was over 3.00 m s^{-1}, peaking in January (Table 1).

Insolation (I, h) has a direct influence on the chlorophyll metabolism of plants (Silva et al. 2016). In the first cycle, insolation was the highest in October and the lowest in June. During regrowth, insolation was the lowest in May and the highest in March. The highest precipitation (P, mm) in the first cycle occurred in March and the lowest in October, with an annual rainfall of 551.20 mm, which is within the adequate range for forage cactus - 368.4 to 812.4 mm $year^{-1}$ (Souza et al. 2008). Precipitation during regrowth was 262.5 mm over the five evaluation months, which is within the proper range for forage cactus (Table 1).

The non-destructive green matter biomass estimations of cladodes (g) presented a monthly progression for irrigation frequencies in the first cycle, showing superiority for plants irrigated every 7 days. That is because the higher water supply enhances plant development, consequently increasing the amount of biomass (Table 2).

Table 2. Mean, maximum, and minimum non-destructive green matter biomass estimations of forage cactus in the first cycle according to irrigation frequency and evaluation periods.

Irrigation frequency	Evaluation period	Mean±SD (g)	CV (%)	Maximum (g)	Minimum (g)
7 days	January	508.10±219.79^{f}	43.26	1,766.36	106.41
	February	683.89±285.93^{e}	41.81	2,144.60	109.09
	March	792.87±342.72^{d}	43.22	2,526.53	163.79
	April	1,048.28±613.57^{c}	58.53	6,280.90	347.16
	May	1,192.78±616.73^{c}	51.70	6,351.95	319.88
	June	1,367.57±809.36^{b}	59.18	6,682.79	400.13
	July	1,513.86±895.79^{a}	59.17	7,004.92	463.52
	August	1,519.66±897.47^{a}	59.06	7,004.92	463.52
	September	1,542.88±902.66^{a}	58.52	7,004.92	463.52
	October	1,555.03±904.79^{a}	58.19	7,004.92	463.52
	November	1,587.16±906.80^{a}	57.13	7,004.92	463.52
	December	1,574.90±908.67^{a}	57.69	7,004.92	463.52
28 days	January	348.59±138.66^{g}	39.78	1,058.98	110.75
	February	489.73±181.58^{f}	37.08	1,206.00	144.45
	March	575.34±221.16^{f}	38.43	1,492.12	155.04
	April	830.77±289.80^{e}	34.88	1,647.80	160.50
	May	982.75±327.43^{d}	33.32	1,925.68	177.19
	June	1,190.96±375.16^{c}	31.50	2,224.53	235.13
	July	1,291.38±389.75^{b}	30.18	2,160.76	236.74
	August	1,298.58±391.26^{b}	30.13	2,173.71	236.74
	September	1,313.18±389.71^{a}	29.68	2,214.20	236.74
	October	1,326.95±385.67^{a}	29.06	2,325.97	332.24
	November	1,354.66±399.48^{a}	29.49	2,661.95	353.58
	December	1,378.91±417.53^{a}	30.28	2,676.39	353.58
p-value					
Irrigation frequency (I)		< .0001			
Evaluation period (E)		< .0001			
I*E		0.9999			

Lowercase letters in the column differ by Tukey's test at a 5% probability level.

The analysis of non-destructive green matter biomass estimation during regrowth demonstrates that plants are more adaptable, considering the lack of significant differences in irrigation frequencies and evaluation times at 5% probability by Tukey’s test (Table 3). Irrigation frequencies presented significant differences at 5% probability by Tukey's test in primary and secondary cladodes; height, width, and thickness of the mother cladode; width and thickness of primary and tertiary cladodes; and height, width, and thickness of secondary cladodes (Table 5). The evaluation periods did not influence tertiary cladodes, as well as the height, length, and thickness of mother and tertiary cladodes. The interaction between irrigation frequencies and evaluation periods affected the primary cladodes, especially their thickness (Table 5).

Table 3. Mean, maximum, and minimum non-destructive green matter biomass estimations of forage cactus during regrowth according to irrigation frequency and evaluation periods.

Irrigation frequency	Evaluation period	Mean±SD (g)	CV (%)	Maximum (g)	Minimum (g)
7 days	January	64.70±44.54^{e}	65.79	250.38	13.48
	February	158.36±61.29^{d}	38.71	422.00	77.04
	March	305.84±134.01^{c}	43.82	765.26	120.38
	April	509.11±211.51^{b}	41.54	1022.39	246.53
	May	712.77±278.37^{a}	39.06	1320.38	249.79
28 days	January	71.74±35.40^{e}	49.34	202.23	3.21
	February	171.52±66.34^{d}	38.68	333.84	51.36
	March	289.13±122.97^{c}	42.54	706.63	134.82
	April	480.90±175.82^{b}	36.56	956.58	147.34
	May	695.44±340.82^{a}	49.00	1767.21	176.87
		p-value			
Irrigation frequency (I)				0.5777	
Evaluation period (E)				< .0001	
I*E				0.9263	

Table 4. Forage cactus cultivar *Opuntia stricta* (Haw.) Haw. yields according to irrigation frequency in the first cycle.

Irrigation frequency (days)	Partial field weight (48 plants - kg)	Total field weight (216 plants - kg)	Total green mass weight (ton ha^{-1})
7	624.22	2.730.95	240.81
28	486.24	2.127.30	187.58

4. Discussion

Irrigation frequency influences the emergence of primary, secondary, and tertiary cladodes, corroborating the data from Silva et al. 2015, Rocha et al. 2017, Silva et al. 2019, and Nunes et al. 2019. Plants irrigated every 7 days present a higher number of primary cladodes (4.38 u), 11.45% higher than those irrigated every 28 days, and secondary cladodes increased by 26.94% (Table 5). That is due to the higher relative water content of plants irrigated every 7 days, as water restriction reduces the relative water content, thickness, and growth of cladodes (Scalisi et al. 2016; Nunes et al. 2020). However, that was not the case for the number of tertiary cladodes. Lima et al. 2021 reported that the performance of this forage cactus is associated with its presence in phenophase II, which corresponds to the period between the emission of second- and third-order cladodes. At this stage, tertiary cladodes are still young and in their initial development phase.

Irrigation frequency also influences the structural characteristics of the forage cactus, affecting plant height (Silva et al. 2014; Silva et al. 2015), width (Rocha et al. 2017; Silva et al. 2019), and thickness (Nunes et al. 2019; Nascimento et al. 2020; Matos et al. 2020). The highest effects were observed in plants irrigated every 7 days, with increases of 8.59% in height, 17.34% in width, and 4.38% in thickness for the mother cladode, and 5.23%, 4.24%, and 8.44%, respectively, for secondary cladodes (Table 5). In primary and tertiary cladodes, the 7-day irrigation frequency also resulted in higher values, with increases of 2.36% and 18.23% in height and 5.16% and 15.00% in thickness, respectively. Width did not differ significantly among irrigation frequencies (Table 5).

Table 5. Morphometric characteristics of the first cycle of forage cactus according to irrigation frequencies and evaluation periods.

Effect (days)	Cladode			Mother cladode			Primary cladode			Secondary cladode			Tertiary cladode		
	Prim. (u)	Sec. (u)	Tert. (u)	H (cm)	W (cm)	T (mm)	H (cm)	W (cm)	T (mm)	H (cm)	W (cm)	T (mm)	H (cm)	W (cm)	T (mm)
Irrigation frequency															
7	4.38^{a}	5.56^{a}	2.94^{a}	21.62^{a}	26.94^{a}	1.49^{a}	34.81^{a}	26.47^{a}	1.02^{a}	26.60^{a}	21.90^{a}	0.90^{a}	23.61^{a}	19.76^{a}	0.69^{a}
28	3.93^{b}	4.38^{b}	2.70^{a}	19.91^{b}	25.81^{b}	1.27^{b}	34.01^{b}	26.94^{a}	0.97^{b}	25.28^{b}	21.01^{b}	0.83^{b}	19.97^{b}	17.27^{a}	0.60^{b}
Evaluation period															
January	2.28^{d}	-	-	20.78^{a}	26.43^{a}	1.18^{a}	16.75^{f}	11.05^{f}	0.62^{f}	-	-	-	-	-	-
February	2.92^{c}	1.00^{c}	-	20.78^{a}	26.43^{a}	1.18^{a}	25.87^{e}	19.43^{e}	0.73^{e}	10.00^{c}	7.00^{c}	0.40^{b}	-	-	-
March	3.49^{b}	2.09^{bc}	-	20.78^{a}	26.43^{a}	1.18^{a}	29.17^{d}	21.98^{d}	0.80^{d}	14.55^{bc}	12.27^{bc}	0.56^{ab}	-	-	-
April	4.35^{a}	4.33^{abc}	-	20.76^{a}	26.37^{a}	1.28^{a}	34.18^{c}	26.11^{c}	0.98^{c}	16.56^{bc}	13.16^{b}	0.43^{ab}	-	-	-
May	4.46^{a}	4.53^{abc}	1.00^{a}	20.76^{a}	26.37^{a}	1.28^{a}	35.88^{b}	27.68^{b}	1.03^{b}	18.70^{b}	15.59^{b}	0.75^{ab}	27.00^{a}	22.00^{a}	0.50^{a}
June	4.51^{a}	4.62^{abc}	1.00^{a}	20.76^{a}	26.35^{a}	1.37^{a}	37.24^{a}	29.19^{a}	1.06^{ab}	26.12^{a}	21.53^{a}	0.86^{ab}	31.00^{a}	24.00^{a}	0.90^{a}
July	4.52^{a}	4.74^{ab}	1.00^{a}	20.76^{a}	26.35^{a}	1.37^{a}	38.25^{a}	30.18^{a}	1.09^{a}	27.97^{a}	23.11^{a}	0.95^{a}	31.00^{a}	24.00^{a}	1.10^{a}
August	4.52^{a}	4.70^{abc}	1.00^{a}	20.76^{a}	26.35^{a}	1.37^{a}	38.25^{a}	30.19^{a}	1.09^{a}	27.76^{a}	22.98^{a}	0.93^{ab}	13.60^{a}	11.80^{a}	0.44^{a}
September	4.52^{a}	4.76^{ab}	1.88^{a}	20.76^{a}	26.35^{a}	1.37^{a}	38.28^{a}	30.21^{a}	1.09^{a}	28.01^{a}	23.21^{a}	0.94^{a}	21.43^{a}	17.71^{a}	0.69^{a}
October	4.53^{a}	5.04^{ab}	2.29^{a}	20.76^{a}	26.35^{a}	1.37^{a}	38.27^{a}	30.20^{a}	1.09^{a}	28.36^{a}	23.58^{a}	0.95^{a}	17.88^{a}	15.35^{a}	0.52^{a}
November	4.58^{a}	5.97^{a}	3.19^{a}	20.76^{a}	26.35^{a}	1.37^{a}	38.27^{a}	30.20^{a}	1.09^{a}	28.68^{a}	23.79^{a}	0.92^{ab}	20.02^{a}	17.49^{a}	0.49^{a}
December	4.58^{a}	5.97^{a}	3.19^{a}	20.76^{a}	26.35^{a}	1.37^{a}	38.27^{a}	30.20^{a}	1309^{a}	28.68^{a}	23.79^{a}	0.92^{ab}	25.91^{a}	21.61^{a}	0.87^{a}
MSE	1.48	3.59	2.65	4.86	3.83	1.56	5.60	4.58	0.17	6.77	5.13	0.52	8.20	6.82	0.26
p-value															
Irrigation frequency (I)	< .0001	< .0001	0.6660	< .0001	< .0001	< .0001	< .0001	0.5762	< .0001	< .0001	< .0001	< .0001	0.0314	0.0683	0.0207
Evaluation period (E)	< .0001	< .0001	0.4422	1.000	1.000	0.7300	< .0001	< .0001	< .0001	< .0001	< .0001	< .0001	0.5231	0.5892	0.5236
I*E	0.3989	1.0000	0.9592	1.000	1.000	0.9878	0.0318	0.5273	< .0001	0.0002	0.0002	0.9719	0.7379	0.7371	0.6128

Different letters in the column differ by Tukey's test at a 5% probability level; Prim. – primary; Sec. – secondary; Tert – tertiary; H - height; W - width; T – thickness; u - unit; MSE – mean standard error.

The evaluation periods did not affect the growth dynamics of the mother cladode, which maintained the same height, width, and thickness (Table 5), possibly because it is a formed cladode, which roots in less than a month and appears as primary cladodes, corresponding to phenophase I (FV1) of its vegetative development, from planting to the emission of the secondary cladode (Lima et al., 2021). The evaluation periods significantly affected ($p > 0.05$) the number of primary and secondary cladodes, which have grown progressively over the months, with few variations after June (Table 5), and without significant statistical differences.

Primary cladodes achieved higher rates in height (14.65%), width (15.82%), and thickness (18.36%) between March and April, which may be due to the higher rainfall during these months: 173.40 mm in March and 97.20 mm in April (Table 5). This period also corresponds to the four months after planting, when filling or higher plant growth occurs. A similar situation occurred for secondary cladodes, which exhibited higher rates of height (28.41%) and width (27.58%) between May and June, which may also be due to extensive rainfall during these months: 65.60 and 84.90 mm, respectively.

There was an interaction effect between irrigation frequency and evaluation period on the height and thickness of primary cladodes, as well as height and width of secondary cladodes, without an interaction between the other evaluated factors (Table 5).

During regrowth, irrigation frequency did not affect the morphometric variables of forage cactus cladodes. However, the evaluation periods had a significant effect ($p < 0.05$, Tukey's test) on the primary cladodes, as well as on the height, width, and thickness of primary and secondary cladodes. The interaction between the factors did not produce an effect (Table 6). Irrigation frequencies did not significantly differ in absolute terms. The number of cladodes in the 7-day irrigation interval was 6.25% higher than in the 28-day interval. This difference may be related to the high rainfall observed during the study period, which likely allowed plants irrigated every 28 days to retain more water in their tissues.

Table 6. Morphometric characteristics of irrigated forage cactus regrown every 7 and 28 days.

Effect	Cladode		Primary cladode			Secondary cladode		
	Prim. (u)	Sec. (u)	H (cm)	W (cm)	T (mm)	H (cm)	W (cm)	T (mm)
Irrigation frequency (days)								
7	10.20^{a}	6.26^{a}	28.84^{a}	22.06^{a}	0.74^{a}	19.29^{a}	16.27^{a}	0.54^{a}
28	9.60^{b}	6.67^{a}	29.02^{a}	22.15^{a}	0.73^{a}	20.03^{a}	16.69^{a}	0.72^{a}
Evaluation period								
January	8.86^{c}	-	18.23^{e}	14.67^{e}	0.45^{e}	-	-	-
February	9.42^{bc}	1.00^{a}	25.82^{d}	20.26^{d}	0.57^{d}	5.00^{b}	5.00^{b}	4.33^{b}
March	10.14^{ab}	2.19^{a}	31.28^{c}	23.06^{c}	0.73^{c}	9.85^{b}	9.85^{b}	7.92^{b}
April	10.40^{ab}	7.06^{a}	33.58^{b}	25.51^{b}	0.92^{b}	19.19^{a}	19.19^{a}	16.23^{a}
May	10.69^{a}	7.75^{a}	35.80^{a}	27.07^{a}	1.00^{a}	23.91^{a}	23.91^{a}	20.08^{a}
p-value								
Irrigation frequency (I)	0.0267	0.9422	0.5812	0.7048	0.6661	0.6228	0.5707	0.5108
Evaluation period (E)	0.0001	0.5632	< .0001	< .0001	< .0001	< .0001	< .0001	0.0162
I*E	0.9758	0.9780	0.7172	0.4333	0.8497	0.5228	0.6631	0.3331

Different letters in the column differ by Tukey's test at a 5% probability level; Prim. – primary; Sec. – secondary; H - height; W - width; T – thickness; u – unit.

The chemical composition of primary, secondary, and tertiary cladodes, considering irrigation frequency, did not show statistically significant differences ($p > 0.05$) (Table 7). That is possibly because cladodes belong to the same plant, so they have similar compositions (Almeida, 2012).

Monteiro et al. 2019, Conceição et al. 2018, Silva et al. 2018, and Barros et al. 2017 support that the values of DM, OM (the set of nitrogen and non-nitrogen compounds in the food), MM or ash (the mineral content), NFC, ADF (the least digestible portion of the forage cactus cell wall by rumen microorganisms), and TC are within the adequate range for forage cactus (Table 8).

Air temperature influences photosynthesis and other physiological and biochemical processes in plants (Silva et al. 2016; Souza et al. 2018), which stands out, as it may help stop plant growth. Silva et al.

2015 analyzed the growth and productivity of forage cactus clones in the semi-arid region and the relationships with meteorological variables. They found that the increase in wind speed harms forage cactus growth, which is possibly associated with higher plant transpiration, influencing CO_2 absorption and the mechanical effect on plant cladodes.

Table 7. Averages of dry matter (DM), organic matter (OM), mineral matter (MM), crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), acid detergent fiber (ADF), non-fibrous carbohydrates (NFC), and total carbohydrates (TC) of forage cactus cladodes irrigated every 7 and 28 days.

Primary			
Variable	**7 days**	**28 days**	**p-value**
DM	11.71±1.21[a]	10.71±1.13[a]	0.2740
OM	87.42±0.41[a]	86.41±1.60[a]	0.2672
MM	12.58±0.41[a]	13.59±1.60[a]	0.2672
CP	7.22±0.45[a]	7.08±1.17[a]	0.4697
EE	1.92±0.24[a]	1.71±0.44[a]	0.4375
NDF	51.09±9.74[a]	51.91±8.27[a]	0.9018
ADF	12.57±3.63[a]	9.55±1.94[a]	0.1917
NFC	27.19±10.22[a]	25.08±10.43[a]	0.7821
TC	78.28±0.75[a]	76.99±2.62[a]	0.3818
Secondary			
DM	9.72±1.85[a]	10.28±1.54[a]	0.6550
OM	86.99±1.84[a]	87.65±0.97[a]	0.5521
MM	13.01±1.84[a]	12.36±0.97[a]	0.5521
CP	7.82±0.16[a]	8.76±2.51[a]	0.4859
EE	1.96±0.14[a]	1.51±0.14[b]	0.0039
NDF	42.35±9.17[a]	48.25±10.19[a]	0.4221
ADF	8.99±3.40[a]	9.46±1.37[a]	0.8051
NFC	34.87±10.01[a]	29.14±10.36[a]	0.4566
TC	77.21±1.65[a]	77.39±2.55[a]	0.9107
Tertiary			
DM	9.19±1.92[a]	9.85±1.92[a]	0.6411
OM	88.47±0.80[a]	88.93±1.38[a]	0.5829
MM	11.54±0.80[a]	11.07±1.38[a]	0.5829
CP	9.30±1.86[a]	9.70±2.05[a]	0.7836
EE	1.67±0.16[a]	1.48±0.25[a]	0.2404
NDF	48.28±5.28[a]	40.64±6.63[a]	0.1217
ADF	9.84±1.50[a]	8.42±1.50[a]	0.2316
NFC	29.23±5.00[a]	37.12±8.91[a]	0.1733
TC	77.50±2.70[a]	77.76±2.36[a]	0.8904

Different letters in the row differ by the t-test at a 5% probability level.

Bezerra et al. 2014, Silva et al. 2016, and Souza et al. 2018 state that climate variables, such as temperature, relative humidity, insolation, and precipitation, influence plant growth and development. This study found a significant difference, at a 5% probability level using Tukey's test, in the non-destructive green matter biomass estimation of forage cactus during the first cycle according to irrigation frequency and evaluation periods (Table 2), with no interaction effect between the factors. The non-destructive green matter biomass estimations corroborate Dantas Neto et al. (2020), who evaluated the growth and productivity of forage cactus under different irrigation frequencies and found that the green biomass production in forage cactus decreases as the irrigation frequency decreases (in days).

Thus, the water supplied to forage cactus with a fixed blade every 28 days may be a viable alternative for producers in the semi-arid region, as this region experiences water shortage most of the year. However, if producers can store water and provide a fixed blade every 7 days, production will grow, and livestock will have a proper nutritional supply throughout the year.

The non-destructive green matter biomass estimations during regrowth demonstrate that, from the second year of cultivation (regrowth), the forage cactus cultivar *Opuntia stricta* (Haw.) Haw. can be irrigated every 28 days without compromising yields. Thus, producers in the semi-arid region can save irrigation water and have forage cactus-based feed available throughout the year, which may represent a strategy for living in these regions.

Table 8. Reference values of dry matter (DM), organic matter (OM), mineral matter (MM), crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), acid detergent fiber (ADF), non-fibrous carbohydrates (NFC), and total carbohydrates (TC) for the forage cactus cultivar *Opuntia stricta* (Haw.) Haw.

Reference	DM	OM	MM	CP	EE	NDF	ADF	NFC	TC
Monteiro et al. (2019)	12.30	91.40	-	5.50	-	25.90	-	55.00	-
Peixoto et al. (2018)	-	77.61	13.70	5.15	1.22	-	18.53	-	79.90
Conceição et al. (2018)	10.55	80.25	-	5.55	1.21	29.16	-	40.67	-
Silva et al. (2018)	9.40	88.12	-	6.00	1.27	26.20	-	54.73	-
Barros et al. (2017)	12.20	86.90	-	5.10	1.60	25.70	-	52.80	-

The productivity of forage cactus irrigated every 7 days was 28.38% higher than that of every 28 days.

The yield in tons of green mass per hectare decreases as irrigation frequency increases (Table 4). Dantas et al. 2020 studied the same cultivar, obtaining 60.2 t ha^{-1} at the 7-day interval and 45.3 t ha^{-1} at the 28-day interval. These results corroborate our study when analyzing irrigation frequency. The 7-day frequency provides a higher green mass yield of forage cactus, which producers can apply in the semi-arid region.

The growth dynamics of the forage cactus are closely related to air temperature. Accordingly, plants exposed to suitable air temperatures and higher irrigation frequencies exhibited enhanced development. The growth of tertiary cladodes did not show statistically significant differences, possibly due to their phenophase. However, after June, producers should perform a first cut and supply the animals in the trough, given the stabilization in the growth of primary and secondary cladodes.

Lima et al. 2021 state that the forage cactus cultivar *Opuntia stricta* (Haw.) Haw. In phenophase I (FV1) does not present a significant difference in the number of primary and secondary cladodes because the plants are starting their vegetative development. It is noteworthy that primary cladodes, regardless of the irrigation frequency, have greater heights, widths, and thicknesses than secondary ones due to their age and phenophase (Table 6). These findings corroborate Pereira et al. 2015 and Queiroz et al. 2015, who investigated the effect of different irrigation frequencies on forage cactus without finding significant changes in the forage cactus's agronomic characteristics.

Crude protein and neutral detergent fiber achieved higher means than the reference (Monteiro et al. 2019; Peixoto et al. 2018; Conceição et al. 2018; Silva et al., 2018; Barros et al. 2017) (Table 8), probably due to the higher water supply and base fertilization used in this research.

Ether extract (EE), however, did not behave similarly to the others. This variable represents part of the food energy source, which is significant for growth, vitamin composition, and making the food more palatable to animals. It presented a statistically significant difference ($p < 0.05$) in secondary cladodes, with a higher content in plants irrigated every 7 days compared to those irrigated every 28 days (Table 7). That is due to the higher water availability of plants irrigated every 7 days and the higher radiation input received by secondary cladodes compared to primary and tertiary ones, as edaphoclimatic conditions may alter the chemical composition, and younger cladodes may have lower EE content (Alves et al. 2017).

5. Conclusions

The 7-day irrigation frequency shows better responses regarding the morphometric characteristics of the forage cactus cultivar *Opuntia stricta* (Haw.) Haw.

Regarding the evaluation period, the first cut can be made in the forage cactus cultivar *Opuntia stricta* (Haw.) Haw. after July in the first cycle, considering the lack of significant differences after this month.

Irrigation at a low frequency and low water volume promotes satisfactory yields in forage cactus cultivated in a semi-arid environment.

The irrigated forage cactus presented adequate bromatological content for supplying livestock in the semi-arid region.

Authors' Contributions: MIRANDA, J. R.: conception and design, acquisition of data, analysis and interpretation of data, and drafting the article; FURTADO, A.D.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, and critical review of important intellectual content; SILVA, V.C.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, and critical review of important intellectual content; ARAUJO, J.S.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, and critical review of important intellectual content; NEVES, R.S.: analysis and interpretation of data, and critical review of important intellectual content; OLIVEIRA FILHO, T.O.: analysis and interpretation of data, drafting the article, and critical review of important intellectual content. All authors have read and approved the final version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Ethics Approval: Not applicable.

Acknowledgments: We thank the Paraíba State Research Support Foundation (FAPESQ-PB) for funding the research (FAPESQ-PB), process no. 2025/1830. And the National Institute of the Semi-Arid Region and the Coordination for the Improvement of Higher Education Personnel (CAPES) for the scholarship.

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