Physiology of the forage cactus cultivate *Opuntia stricta* (*Haw.*) *Haw* under different irrigation frequencies in the Semiarid[1]

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ABSTRACT

The objective of this work was to evaluate the physiological variables of the cultivar Opuntia stricta (Haw.) Haw in the first cycle and in the regrowth, under different frequencies of drip irrigation, cultivated in the Agreste da Paraíba mesoregion. Therefore, a randomized block design was used, with 2 treatments (irrigation frequencies) and 4 replications (blocks), with each treatment repeated 3 times within the block (triplicate) totaling 24 experimental plots. For physiological variables, data were evaluated by analysis of variance (ANOVA) and means compared by t test at 5% probability using SAS ® (2002). The present study shows that the stress of environmental conditions had a greater impact on the frequency of irrigation every 28 days, since the forage cactus irrigated every 7 days had the highest internal concentration of CO2; CO2 absorption rate; instant efficiency in water use; intrinsic efficiency of water use; instantaneous carboxylation efficiency, both in the first cycle and in the regrowth period. Respiratory rate and stomatal conductance did not differ between irrigation frequencies for both cycles, showing the good adaptation of the cultivar to the semiarid region.

Keywords: plant welfare; cactus; water deficit; abiotic stress; forager.

INTRODUCTION

The semiarid region is characterized by low rainfall, irregular distribution of rainfall and long periods of drought. In this sense, forage cactus has physiological advantages to adapt to this region, showing rusticity, adaptability and high efficiency in water use when subjected to water stress, commonly cultivated in rainfed conditions (Rodriguez *et al.*, 2015; Rodrigues *et al.*, 2016; Bacalhau *et al.,* 2017).

Considering that plant development is the result of the relationship between the availability of water, soil nutrients and the environment and that physiological and biochemical processes are directly influenced by climatological variables, the climate of the semiarid region can negatively affect production, productivity and plant development, therefore, it is essential to implement and use cultures adapted to semi-arid regions to avoid productive losses of herds (Rodriguez *et al.*, 2015; Bacalhau *et al.*, 2017; Souza *et al.*, 2018), as well as the use of techniques such as irrigation, which even at low volume promotes changes in the physiology and growth dynamics, increasing its yield, quality and productivity (Consoli *et al.*, 2013; Silva *et al.*, 2014; Lima *et al.*, 2015; Lima *et al.*, 2016; Cruz Neto *et al.*, 2017; Rocha *et al.*, 2017).

The cultivate *Opuntia stricta (Haw.) Haw* emerges as an alternative for the semiarid region, due to its adaptation

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to the climate and its anatomical, morphological and physiological characteristics, such as the high efficiency in the use of water that makes it an important forage resource for the livestock in arid and semi-arid regions, in addition to the excellent acceptability by animals, high energy levels, high concentration of water and minerals, high productivity per unit of area, high phytomass production, in addition to being a plant without thorns and resistant to carmine mealybug. (Araújo *et al.*, 2010; Silva *et al.* 2014; Rodriguez *et al.*, 2015; Bacalhau *et al.*, 2017; Marques *et al.,* 2017; Souza *et al.*, 2018; Nogueira de Sá *et al.*, 2021).

The efficiency in the use of water in forage cactus is due to its way of assimilating $_{CO2,}$ through the crassulacean acid metabolism (CAM), which opens the stomata at night in mild temperatures, to capture and fix CO_2 and, during day with the stomata closed and at high temperatures, it incorporates CO_2, preventing the loss of water and increasing its use, enabling its production in arid and semi-arid regions (Rodrigues *et al.*, 2016; Taiz *et al.*, 2017).

When there is greater availability of water, as in irrigated forage cactus, a gradual transition from CAM metabolism to C3 metabolism can occur, where the culture acts as a facultative CAM, opening its stomata in the early morning hours under favorable environmental conditions (Liguori *et al.*, 2013; Taiz *et al.*, 2017). The physiological processes of plants are directly influenced by climatic variables, soil temperature variation, also interfering with germination, root growth and the absorption of water and nutrients by plants (Hillel, 1998; Silva *et al.*, 2016; Souza *et al.*, 2018).

Therefore, the objective of this work was to evaluate the physiological variables of the cultivate *Opuntia stricta (Haw.) Haw* in the first cycle and in the regrowth, under different frequencies of drip irrigation, cultivated in the Agreste da Paraíba mesoregion.

MATERIAL E METHODS

Characterization of the experimental area

The experiment took place at the Experimental Farm of the National Institute of the Semiarid (INSA), located in the municipality of Campina Grande - PB, in the mesoregion of Agreste, whose coordinates are South latitude 07º 14’ 00’’ and West longitude 35º 57’ 00’’, with an altitude of 491 m, and the climate of the region classified as As according to the Koppen classification (Francisco *et al.*, 2015).

Experimental area soil

According to the criteria of the Brazilian System of Soil Classification - SiBCS (Embrapa, 2013), the soil of the experimental area is classified as Planosol haplic and, for its analysis, 15 simple samples were collected at different points, in depths from 0 to 20 cm (Santos *et al.*, 2017), which underwent homogenization, resulting in a single sample, packed in a properly identified plastic bag and sent to the Irrigation and Salinity Laboratory of the Federal University of Campina Grande to carry out the physical-chemical characterization of the soil (Table 1).

Before the implantation of the crop, the soil was submitted to the plowing and harrowing processes and, after the analysis, fertilization was carried out, using 200 kg of urea, 40 kg of monoammonium phosphate (MaP) and 60 kg of granulated potassium chloride, distributed from homogeneously in the area.

Irrigation water

The analysis of irrigation water was carried out in the Irrigation and Salinity Laboratory of the Federal University of Campina Grande, classified as C1, which corresponds to low salinity water (Bernardo, 1995).

Cultivate used and form of planting

Racquets of forage cactus cultivate *Opuntia stricta (Haw.) Haw*, from INSA and free from infestations by pests and diseases, were used. injuries caused by cutting in the field, being the planting performed in a groove with bilateral alignment (Dominó).

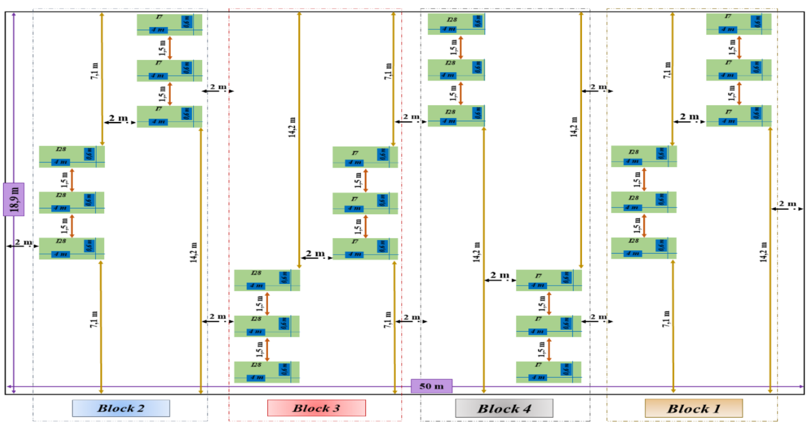
Experimental design and treatments

The experimental period was 17 months, comprising the first year of the forage cactus cycle (January to December 2020) and the first five months of regrowth, the second year of the cactus cycle (January to May 2021). The experimental design in randomized blocks (DBC) with 2 treatments (I7 - frequency of irrigation every 7 days and I28 - frequency of irrigation every 28 days) and 4 repetitions (number of blocks), with each treatment repeated 3 times within of the block (triplicate) totaling 24 experimental plots (Figure 1).

Table 1: Physicochemical soil characterization

Chemical Characteristics		Physical characteristics	
Ca (meq/100g de soil)	1,85	Sand (%)	82,16
Mg (meq/100g de soil)	2,54	Silt (%)	16,08
Na (meq/100g de soil)	0,17	Clay (%)	1,76
K (meq/100g de soil)	0,49	Texture	Free Sand
S (meq/100g de soil)	5,05	DS (g/cm^3)	1,34
H (meq/100g de soil)	0,40	DP g/cm^3	2,68
Al (meq/100g de soil)	0,24	Porosity %	50,00
T (meq/100g de soil)	5,69	**Humidity (%dry soil base)**	
CCQ	Absence	Natural	0,54
CO %	0,78	0,10 atm	
MO %	1,34	0,33 atm	13,01
N %	0,08	1,00 atm	
P assimilable mg/100g	0,18	5,00 atm	
pH H20 (1:2,5)	5,57	10,0 atm	
pH KCl (1:2,5)		15,0 atm	5,62
CE – mmhos/cm (Ground-Water Suspension)	0,16	AD	7,39
pH (Saturation extract)	5,05		
CE – mmhos/cm (Saturation extract)	0,59		
Chloride (meq/l)	3,75		
Carbonate (meq/l)	0,00		
Bicarbonate (meq/l)	0,40		
Sulfate (meq/l)	Absence		
Ca (meq/l)	2,00		
Mg (meq/l)	1,25		
K (meq/l)	0,55		
Na (meq/l)	2,40		
Saturation percentage	21,66		
Sodium Adsorption Ratio	1,88		
PSI	2,99		
Salinity	Not saline		
Soil class	Normal		

Ca – calcium; Mg – magnesium; Na – sodium; K – potassium; S – sulfur; H – hydrogen; Al – aluminum; CCQ – qualitative calcium carbonate; CO – organic carbon; MO – organic matter; N – nitrogen; P – phosphor; CE – electric conductivity; DS – soil density; DP – particle density; AD – available water.



I7 - Irrigated every 7 days; *I28* - Irrigated every 28 days.

Figure 1: Total distribution of experimental blocks.

Each experimental plot consisted of a double row with 18 plants, 9 per row, with 2.4 m² of planted area, the spacing between rows was 0.6 m and 0.5 m between plants, with 4 m in length, 0.75 m of border on the sides and 1 m of upper and lower borders, with total area per experimental plot, considering borders of 12.6 m² (Figure 2).

Irrigation management

Irrigation was done by drip, with GA 4 type drippers, distributed in rows close to the plants every 0.5 m and the hose used as a pipe had 17 mm of internal diameter, in the afternoon between 15:00 and 16:30 h.

Irrigation management for irrigated forage cactus every 7 days took place through a fixed weekly depth of 8.74 mm, which corresponds to 35.96 mm month^{-1}, this being a complement to the weekly precipitation, that is, if it had rained the volume equal to or greater than necessary, weekly irrigation was discarded, otherwise it was performed. For experimental plots irrigated every 28 days, a volume of 8.74 mm was used, which was distributed every 28 days.

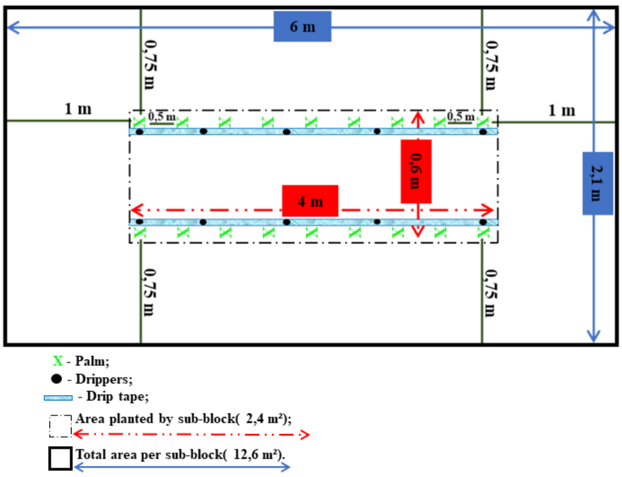


Figure 2: Distribution of total and planted area per sub-block.

Physiological analysis

Physiological variables of gas exchange in forage cactus, stomatal conductance (gs) (mol m^{-2} s^{-1}), transpiration rate (E) (mmol H2O m^{-2} s^{-1}), CO_2 uptake rate (A) (μmol m^{-2} s^{-1}) and internal CO_2 concentration (Ci) (μmol CO_2 mol^{-1}). Based on the data, the instantaneous efficiency of water use (EUA) was calculated, relating the rate of CO_2 uptake with transpiration (A/E), the intrinsic efficiency of water use (EIUA), by the relationship between rate of CO_2 capture and stomatal conductance (A/gs), in addition to the instantaneous carboxylation efficiency (Eci), relating the CO_2 capture rate with the internal carbon concentration (A/Ci).

The gas exchange determinations took place in December 2020 for the first cycle and in May 2021 for regrowth, between 21:00 and 0:00 h, according to the Nobel (2001) methodology, because forage cactus is regulated by crassulacean acid metabolism (CAM), their CO_2 uptake is more intense in this interval. The measurements took place in the plants under irrigation frequency of 7 and 28 days, with one plant randomly chosen in each sub-block, totaling 12 irrigated plants every 7 and 12 every 28 days, in the four experimental blocks. Readings were performed on one mature cladode per plant, characterized by sustaining one or more young cladodes.

To carry out the evaluations, a portable infrared gas analyzer (IRGA) (model LI-COR 6400-XT, Lincon, USA) and tweezers adapted for forage cactus were used (Figure 3). The protocol with the IRGA was: RFA (photosynthetically active radiation) turned off; relative air humidity between 50 – 60%; air flow of 200 μmol s^{-1} and atmospheric CO_2 concentration of 400 μmol mol^{-1}, with leaf chamber dimension of 6.25 cm².

Statistical analysis

For the physiological variables of the first cycle and regrowth, two irrigation frequencies (7 and 28 days) were used, the data obtained were evaluated by analysis of variance (ANOVA) and the means were compared by the t test at the 5% probability, through the SAS® (2002), GLM (General Linear Model) procedure.

RESULTS AND DISCUSSION

In the first cycle of the forage cactus cultivate *Opuntia stricta (Haw.) Haw*, in December 2020 (Table 2) and in the regrowth in May 2021, the temperatures were within the appropriate range for forage cactus, which is from 18 to 32 ºC (Bezerra *et al.*, 2014), having a direct influence on photosynthesis and on other physiological and biochemical processes of plants (Silva *et al.*, 2016; Souza *et al.*, 2018).

The relative humidity of the air (RH, %), a variable that acts on the development of plants, was superior to that recommended for forage cactus, both in the evaluation of the first cycle and in the regrowth (Table 2), of 37.3 and 63.1% according to Souza *et al.* (2008). The wind speed (WS, m s^{-1}), a variable that can affect the evapotranspiration rates of cactus forage, was higher in December in the physiological evaluation of the first cycle, being higher than recommended for these forages that is from 1 to 3 m s^{-1} (Silva *et al.*, 2020). While in the month of physiological evaluation of regrowth, WS was within the range considered adequate for this forage.

Precipitation (P, mm) was lower in December (Table 2), in the evaluation of the physiology of the first cut and higher in the physiological evaluation of regrowth, considered within the recommended range for the forage cactus, which is between 368.4 and 812.4 mm $year^{-1}$ (Souza *et al.*, 2008). In the semiarid region, the months that had lower rainfall levels are those with more intense wind speed (Silva *et al.*, 2015; Silva *et al.*, 2020), which occurred in December in the analysis of the physiology of the first cycle of the forage cactus.

Table 2: Meteorological data from physiological analysis days

	AT (ºC)	RH (%)	WS (m s^{-1})	I (h)	P (mm)
03/12/2020	23,9	84,2	4,1	5,2	0,6
31/05/2021	22,3	93,9	2,5	3	3,2

Source: National Institute of Meteorology - Inmet.
AT (ºC) - average ambient temperature; RH (%) - average relative humidity; WS (m s^{-1}) - wind speed; I (h) - insolation; P (mm) - precipitation.

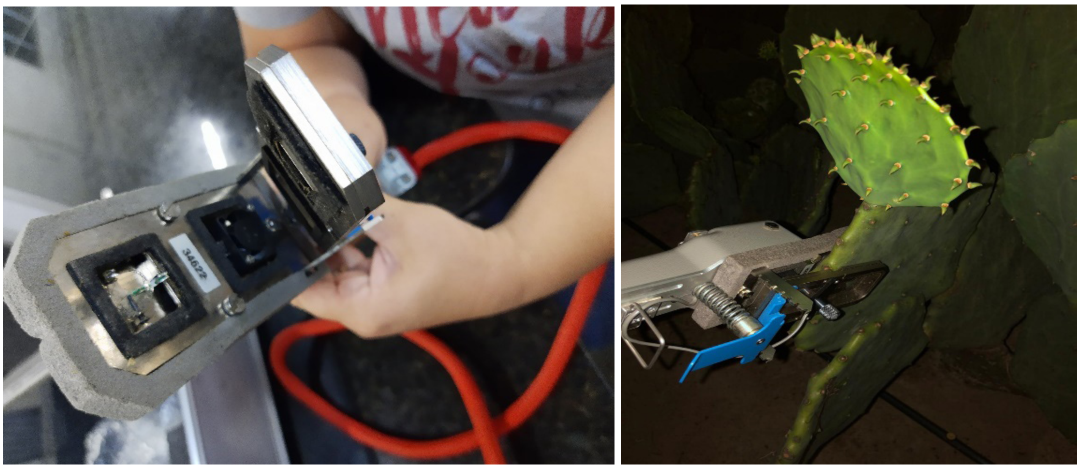


Figure 3: Tweezers adapted for physiological analysis of forage cactus.

The forage cactus have specialized their anatomical and physiological structures, such as storage tissues, fast-growing roots, controlled transpiration and nocturnal absorption of CO_2), to be able to survive in environments unfavorable to the maintenance of water status (Lina & Eloisa, 2018; Jardim *et al.*, 2021).

The insolation (I, h) variable associated with chlorophyll metabolism (Lima Junior *et al.*, 2005; Belúcio *et al.*, 2014; Silva *et al.*, 2016) was higher in December (Table 2) and lower in the month of physiological analysis of regrowth.

High fluorescence values for non-photochemical quenching reflect the photoprotective action of plants, which increases during exposure to high light density, favoring oxidative protection over the oxygen generated in the chlorophyll. In hostile environments, increasing fluorescence values for non-photochemical quenching is an alternative for energy dissipation linked to the xanthophyll cycle; although cacti show excellent adaptation to these ecosystems, especially of the Opuntia genus, to large day and night temperature amplitudes, which compromises energy efficiency and CO_2 fixation (Ojeda-Pérez *et al.*, 2017; Jardim *et al.*, 2021)

The internal concentration of CO_2 (Ci) was higher ($P < 0.05$) in forage cactus with higher frequency of irrigation, being 2.94% higher in the first cycle (Table 3) and

2.69% higher in regrowth (Table 3). According to Taiz *et al.* (2017) forage cactus subjected to lower frequency of irrigation tend to reduce the opening of the stomata and, consequently, the internal concentration of CO_2, however, they were within the concentration considered adequate for forage cactus grown in the semiarid region, which should be greater than 249.0 µmol de CO_2 mol^{-1} (Souza *et al.*, 2020; Alves *et al.*, 2020; Silva, 2019).

Table 3: Physiological variables of irrigated forage cactus at 7 and 28 days and Physiological variables of regrowth every 7 and 28 days

Variables	Irrigation (days)		P value
	7 days	28 days	
Ci (µmol de CO_2 mol^{-1})	388,50 ± 2,50a	377,08 ± 4,36b	< .0001
E (mmol de H_2O m^{-2} s^{-1})	1,12 ± 0,13a	1,18 ± 0,17a	0,2819
Gs (mol m^{-2} s^{-1})	0,20 ± 0,02a	0,20 ± 0,02a	0,7426
A (µmol m^{-2} s^{-1})	2,05 ± 0,41a	0,95 ± 0,29b	< .0001
EUA (A/E)	1,87 ± 0,51a	0,82 ± 0,28b	< .0001
EIUA (A/gs)	10,00 ± 1,69a	4,67 ± 1,35b	< .0001
Eci (A/ci)	0,005 ± 0,001a	0,002 ± 0,0008b	< .0001
Variáveis	**Irrigation (days) - Regrowth**		**P value**
	7	**28**	
Ci (µmol de CO_2 mol^{-1})	391,00 ± 7,27a	380,50 ± 5,66b	0,0007
E (mmol de H_2O m^{-2} s^{-1})	0,64 ± 0,15a	0,59 ± 0,10a	0,4140
Gs (mol m^{-2} s^{-1})	0,09 ± 0,03a	0,08 ± 0,01a	0,2932
A (µmol m^{-2} s^{-1})	0,91 ± 0,41a	0,49 ± 0,16b	0,0030
EUA (A/E)	1,41 ± 0,48a	0,83 ± 0,26b	0,0011
EIUA (A/gs)	10,39 ± 3,28a	5,34 ± 3,27b	0,0011
Eci (A/ci)	0,002 ± 0,001a	0,001 ± 0,0004b	0,0027

Different letters on the line differ from each other by t test.
Ci- internal CO_2 concentration; E - respiratory rate; gs - stomatal conductance; A - CO_2 capture rate, EUA (A/E) - instantaneous water use efficiency, EIUA (A/gs) - intrinsic water use efficiency, Eci (A/Ci) - instantaneous carboxylation efficiency.

Internal CO_2 concentrations above 377.0 µmol CO_2 mol^{-1} can be considered high, which can be explained by the fact that these plants have a net photosynthesis rate (A) below 3.09 µmol CO_2 m^{-2} s^{-1}, moment when a smaller amount of CO_2 is being fixed in the carboxylation step (Silva, 2019), corroborating the present research, since this rate was less than 3.09 µmol CO_2 m^{-2} s^{-1} for the frequency of 7 and 28 days.

Respiratory rates (E) and stomatal conductance (gs), which is respiration and water loss through the cladode, respectively, were similar ($P > 0.05$) between forage cactus in treatments with 7 and 28 days of frequency. irrigation, both for the first cycle and for regrowth (Table 3).

The CO_2 uptake rate was 53.66% higher in forage cactus irrigated with irrigation frequency of 7 days in the first cycle (Table 3) and 7.819% in the regrowth period (Table 3), possibly due to the higher existing CO_2 concentration, which takes to a more intense photosynthesis process (Nobel, 2001). This rate is the result of the balance between photoassimilates, compounds produced by photosynthesis and those lost in respiration, used as an energy source by bacteria that fix nitrogen at plant roots (Nunes *et al.,* 2020). The values obtained for CO_2 uptake were within the range cited in articles in the Semiarid region for forage cactus, ranging from 0.67 to 3.57 µmol m^{-2} s^{-1} (Queiroz *et al.*, 2015; Silva, 2019; Souza *et al.*, 2020; Nunes *et al.*, 2020; Alves *et al.*, 2020).

The instantaneous efficiency of water use (EUA) was favored in irrigated forage cactus in the treatment with a frequency of 7 days, 56.15% higher in the first cycle (Table 3) and 41.13% in the regrowth period, this concentration being considered suitable for forage cactus in the semiarid, which is from 0.88 to 2.41 (Souza *et al.*, 2020; Silva, 2019).

The intrinsic water use efficiency (EIUA) in the first cycle of the forage cactus was 53.3% (Table 3) higher in the treatment with a frequency of 7 days and in regrowth

48.60% higher (Table 3), probably due to the situation of greater water supply, being within the range considered adequate for forage cactus in the semiarid region, which ranges from 4.62 to 10.73 (Silva, 2019; Souza *et al.*, 2020). Quantifying the efficiency of the plant's water use is essential to assess how much water is lost in the transpiration process during gas exchange and knowledge about the efficiency of water use by crops is also important for water savings, in arid and semi-arid regions, in view of the scarcity of availability of water resources (Cajazeira *et al.*, 2018).

The instantaneous efficiency of carboxylation (Eci) in the first cycle was 60% higher in irrigated forage cactus with a frequency of 7 days, that is, within the concentration considered adequate for forage cactus in the Semiarid region, which varies between 0.004 and 0.008 (Silva, 2019; Souza *et al.*, 2020; Alves *et al.*, 2020). While in the period of regrowth, it was 50% higher in forage cactus irrigated every 7 days (Table 3), being below those observed for forage cactus s in the Semiarid region.

CONCLUSIONS

The present study shows clear evidence that the stress of environmental conditions had a greater impact on the frequency of irrigation every 28 days, since the forage cactus in the frequency of irrigation every 7 days had the highest internal concentration of CO_2; CO_2 absorption rate; instant efficiency in water use; intrinsic efficiency of water use; instantaneous carboxylation efficiency, both in the first cycle and in the regrowth period.

Respiratory rate and stomatal conductance showed no difference between irrigation frequencies for both cycles, showing the good adaptation of the cultivate *Opuntia stricta (Haw.) Haw* to the semiarid environment due to the greater efficiency in water use.

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