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CROP PRODUCTION

Forage yield, structural responses and chemical composition of spineless cactus Orelha de Elefante Mexicana in different water depths and irrigation frequencies

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ABSTRACT: *The objective was to evaluate the effects of water depths and irrigation frequencies on structural responses, forage yield and chemical composition of spineless cactus Orelha de Elefante Mexicana (OEM) (Opuntia stricta (Haw.) Haw), in adensed crop system. The experimental design was randomized blocks, in subdivided plots (3x4) with 4 replicates. The water depths were (100%, 75%, 50%, and 25% of ETc - crop evapotranspiration) and three water application frequencies (7; 14 and 28 days between irrigations). There was interaction for water use efficiency (WUE) and plant dry mass. Increasing water depths reduced WUE for all irrigation frequencies and plant dry mass was lower for 7 days compared to 14 and 28 days in 25% ETc. Greater water depths increased linearly the plant height and plant width. First and second order cladode length, second order cladode dry mass (kg), fresh mass yield (FMY) (kg ha^{-1}) and dry mass yield (DMY) (kg ha^{-1}) had a quadratic response with the increase in water depth. The FMY and DMY increased up to 77% and 75% ETc, respectively. Irrigation frequency (28 days) promoted greater first order cladode length and cladode dry mass compared to 7 days. Cladode thickness in plant and basal cladode thickness were greater for 7 days compared to 28 days and 14 and 28 days, respectively, without influence on FMY and DMY. Irrigation frequencies from 7 to 28 days promotes similar forage production and water depths up to 77% ETc favors the forage yield for spineless cactus Orelha de Elefante Mexicana receiving supplemental irrigation.*
Key words: *Opuntia stricta (Haw.) Haw. forage, water supplementation.*

Produção de forragem, respostas estruturais e composição química da palma-forrageira Orelha de Elefante Mexicana em diferentes lâminas e frequências de irrigação

RESUMO: *Objetivou-se avaliar os efeitos das lâminas e frequências de irrigação sobre as respostas estruturais, produção de forragem e composição química da palma-forrageira orelha de elefante mexicana (OEM) (Opuntia stricta (Haw.) Haw), em sistema adensado de cultivo. O delineamento experimental foi em blocos casualizados, em parcelas subdivididas (3x4) com quatro repetições. As lâminas de água foram 100%, 75%, 50% e 25% de ETc (evapotranspiração da cultura) e três frequências de aplicação de água (7; 14 e 28 dias entre as irrigações). Houve interação para eficiência de uso da água (EUA), massa seca de planta. A massa seca da planta aumentou com a aplicação de 64% da Etc na frequência de irrigação de 14 dias. O aumento nas lâminas reduziu a EUA para todas as frequências de irrigação e a massa seca de planta foi menor para 7 dias comparado com 14 e 28 dias, com o uso de 25% da ETc. As maiores lâminas de irrigação aumentaram linearmente a altura e a largura da planta. O comprimento dos cladódios da primeira e segunda ordens, a massa seca dos cladódios da segunda ordem, a produção de massa fresca (PMF) (kg ha^{-1}) e a produção de massa seca (PMS) (kg ha^{-1}) tiveram resposta quadrática com o aumento na lâmina de irrigação. O aumento na PMF e PMS ocorreu até 77% e 75% da ETc, respectivamente. A frequência de irrigação (28 dias) promoveu maior comprimento e peso de cladódios da primeira ordem em comparação com sete dias. A espessura de cladódio e a espessura do cladódio basal foram maiores para sete dias comparado a 28 dias e 14 e 28 dias, respectivamente. A frequência de irrigação de 7 a 28 dias promove similar produção de forragem e a lâmina de irrigação até 77% da ETc favorece a produção da palma forrageira Orelha de Elefante Mexicana recebendo suplementação hídrica.*
Palavras-chave: *Opuntia stricta (Haw.) Haw, forragem, suplementação hídrica.*

INTRODUCTION

Spineless cactus (*Nopalea* sp. and *Opuntia* sp.) has its vegetative growth related to rainfall, relative humidity, thermal amplitude, and water content in the soil (SCALISI et al., 2016). According to Nobel (2001), the growth of spineless cactus is climatically related to the occurrence of at least 400 to 800 mm of rain per year. In the Brazilian Semi-arid many areas are restrictive to the cultivation of

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spineless cactus, such as very low rainfall and thermal amplitude (BEZERRA et al., 2015; LUCENA et al., 2016; SOUZA et al., 2018). In recent years, in several locations of Brazilian semi-arid, such as the Submedio of São Francisco, rainfall were very low and despite the high efficiency in the use of water, this low rainfall associated with high temperatures may reduce the forage yield and the longevity of spineless cactus production area.

The water supplementation for spineless cactus is represented by a strategical application of water via irrigation aiming to reduce the risks of loss of the crop and to increase the forage yield. Some studies have shown considerable increase in forage yield in spineless cactus systems using an additional supply of water strategically provided, especially for high density crop system, (REGO et al., 2014; QUEIROZ et al., 2015; ROCHA et al., 2017; PEREIRA et al., 2020), considering the effect of water in the soil decreases the restriction caused by climatic factors (SCALISI et al., 2016).

However, in drylands water is a scarce resource and it is fundamental for agricultural production. Thus, the production systems need to use this natural resource more efficiently. The establishment of adequate water depth and irrigation frequency is an important tool to maximize forage yield using less water.

QUEIROZ et al. (2015) reported the increase in water depth from 0% to 35% ETo (reference evapotranspiration) equivalent to 976 to 1,421 mm (380 days) did not influence the morphological traits and forage yield of spineless cactus Orelha de Elefante Mexicana (OEM) for a crop system with 15,625 plants ha^{-1}, indicating 1,048 to 1,096 mm as enough to provide the productive responses to the crop.

Additionally, CASTRO et al. (2020) evaluated 0% to 75% of ETo equivalent to 680.9 mm (total rainfall) to 1,570 mm for Miúda and Gigante genotypes of spineless cactus and reported the greater fresh and dry mass yield (FMY, DMY) applying 40% to 50% ETo, indicating the positive responses using supplemental irrigation, and also the possibility of adjusting irrigation management in order to save water.

The objective was to evaluate the effect of water depths and irrigation frequencies on structural responses, chemical composition and forage yield of spineless cactus Orelha de Elefante Mexicana.

MATERIALS AND METHODS

The field test was performed at Fazenda Agrocuraçá, in Curaçá-BA, Brazil, in an area already established with spineless cactus Orelha de Elefante Mexicana (OEM) (*Opuntia stricta* (Haw.) with three years of age. During the experimental period the rainfall was 366 mm, ETo (reference evapotranspiration) was 2,288 mm, the average temperature was 26 °C, and the average relative humidity (RH) was 71%.

The experimental design was a randomized block in subdivided plots (3x4) with 4 replicates, with four water depths and three water application frequencies, totaling 48 experimental units. The water depths evaluated were: 100%, 75%, 50% and 25% of ETc (culture evapotranspiration), based on the ETo accumulated during the interval between irrigations and Kc = 0.52 (crop coefficient) (QUEIROZ et al., 2016). The frequencies of water application studied were 7; 14 and 28 days.

The irrigation was complementary to the rainfall, performed by dripping, using a dripper tube with a flat dripper, totaling 999.44 mm, 699.1 mm, 499.72 mm and 249.86 mm, respectively for 100%, 75%, 50% and 25% ETc, during the entire experimental period, which added to the precipitation totaled 1,365.4 mm, 1,065.6 mm, 865.7 mm and 615.86 mm, for 100%, 75%, 50% and 25% ETc, respectively.

The planting density was 50,000 plants ha^{-1}, corresponding to 2,0 m x 0,10 m planting spacing. The soil in the area is classified as Vertisol and the results of the analysis for a 0 to 20 cm layer were: electrical conductivity (EC) = 0.68 mS cm^{-1}; pH = 4.6; P = 8.27 mg dm^{-3}; K = 0.09 $cmol_c$ dm^{-3}; Na = 0.23 $cmol_c$ dm^{-3}; Ca = 3.6 $cmol_c$ dm^{-3}; Mg = 2.6 $cmol_c$ dm^{-3}; H + Al = 4.8 $cmol_c$ dm^{-3}; sum of bases (SB) = 6.50 $cmol_c$ dm^{-3}; cation exchange capacity (CEC) = 11.3 $cmol_c$ dm^{-3}. For the 20 to 40 cm layer: EC = 0.38 mS cm^{-1}; pH = 4.8; P = 4.16 mg dm^{-3}; K = 0.05 $cmol_c$ dm^{-3}; Na = 0.31 $cmol_c$ dm^{-3}; Ca = 3.2 $cmol_c$ dm^{-3}; Mg = 2.0 $cmol_c$ dm^{-3}; H + Al = 4.6 $cmol_c$ dm^{-3}; SB = 5.60 $cmol_c$ dm^{-3}; CEC = 10.1 $cmol_c$ dm^{-3}.

Morphological traits (plant height and width, number, size, weight, and CAI were measured in three plants of the useful area in all cladodes of each plant. Plant height was evaluated using a tape, measuring from the ground level up to the end of the highest cladode. The plant width was also determined using a tape, evaluating the plant from a side to side. All cladodes in each plant were evaluated, counting the total number per plant and per order (first, second, third and fourth orders). Cladodes of first order were above basal cladode, and second, third and fourth were above first, second and third cladode orders, respectively.

Cladodes were individually measured for length and width using a tape to subsequently determine the CAI. Cladode thickness was evaluated using a caliper. The CAI was calculated as follow: (cladode area (cm^2) x number of cladodes per plant) ÷ 10,000 ÷ (E1 x E2), considering 10,000 as conversion factor from cm^2 to m^2 and E1 x E2, the spacing between rows and between plants, respectively (PINHEIRO et al., 2014).

Fresh mass yield (FMY) (kg ha^{-1}) and dry mass yield (DMY) (kg ha^{-1}) were estimated by cutting and weighing three plants per plot (15 plants per treatment), multiplying by the number of plants ha^{-1}. Plant cut was performed maintaining the basal cladode and the forage material was weighted to determine plant dry mass (kg $plant^{-1}$). Additionally, all cladodes in each plant were weighed to determine cladode dry mass per order (kg).

Water use efficiency (WUE) was estimated considering the rainfall volume plus the volume of water applied by irrigation along 12 months, and the dry mass yield (kg ha^{-1}).

Samples were dehydrated in a forced ventilation oven at 55 °C until constant weight and ground through a 1 mm screen in a mill. The dry matter (DM, method 967.03), ash (method 642.05), crude protein (CP, method 981.10) were determined according to AOAC, (1990), neutral detergent fiber (NDF), and *in vitro* dry matter digestibility (IVDMD) according to Van Soest et al. (1991), with approval by the Ethics Committee on the Use of Animals (CEUA) of Embrapa Semiárido (Protocol 10/2017). The sampling for chemical and IVDMD analysis was performed considering all cladode orders.

The monitoring of soil moisture was performed immediately before and after irrigation events, using the TDR (Time Domain Reflectometry) equipment and it was measured at the 0-20 cm layer, during August and September 2018, lasting 28 days, in which each assessment was weekly (Table 1).

The data were submitted to analysis of variance and Tukey test. A regression analysis was performed for water depths. The software used was the *Statistical Analysis System* - SAS (2009), considering as significant probability values below 5% ($P<0.05$).

RESULTS AND DISCUSSION

There was interaction (water depths and irrigation frequency) on plant dry mass, first order cladode dry mass and WUE. There was no interaction on plant height, plant width, total number of cladodes, CAI, cladode length, width and thickness, considering the average in plant and per order. Forage yield, chemical composition and IVDMD of spineless cactus were also not influenced by interaction (Table 2).

The most frequent irrigation interval (7 days) promoted greater WUE compared to 14 and 28 days for 25% ETc, while for 100% ETc the irrigation frequency of 7 days reduced WUE compared to 14 and 28 days (Table 2). These results are attributed to the water availability in the soil, which the lower water depth (25%) in the irrigation interval of 7 days promoted 7% to 26% of soil humidity, while for 28 days it ranged from 1% to 27% (Table 1), influencing the physiological responses of plant. The water deficit promotes stomatal closure and reduces CO_2 to photosynthesis (TAIZ et al., 2017). The high soil humidity for 100% ETc and 7 days of irrigation interval reduced WUE, demonstrating spineless cactus does not have all this water requirement, indicating the amount of water

Table 1 - Soil humidity (%) with spineless cactus Orelha de Elefante Mexicana (*Opuntia stricta* (Haw.) Haw) in different water depths and irrigation frequencies, before and after irrigation, in Curaça, BA.

----------Soil depth (0 cm – 20 cm) ----------										
Frequency (days)	----------Water depth (% ETc)----------									
	-------25%-------		-------50%-------		---------75%--------		--------100%-------		-----Average-------	
	BI	AI	BI	AI	BI	AI	BI	AI	BI	AI
7	9	16	10	18	11	23	13	25	10.7	20.5
14	6	19	8	22	8	23	9	26	7.75	22.5
28	1	27	2	28	3	28	4	28	2.5	27.7
Average	5.3	20.7	6.7	22.7	7.3	24.7	8.7	26.3		

ETc = Evapotranspiration of culture. BI = before irrigation. AI = after irrigation.

Table 2 - Interaction of water depths and irrigation frequency for plant dry mass, first order cladode dry mass, and water use efficiency of spineless cactus Orelha de Elefante Mexicana.

Irrigation frequency	Water depths, % ETc			
	25%	50%	75%	100%
Plant dry mass, kg				
7 days	0.338 B	0.448 A	0.358 B	0.430
14 days	0.442 A	0.350 AB	0.444 AB	0.510
28 days	0.430 AB	0.346 B	0.468 A	0.420
First order cladode dry mass, kg				
7 days	0.142 B	0.190	0.152	0.194
14 days	0.218 A	0.188	0.208	0.242
28 days	0.274 A	0.178	0.202	0.204
Water use efficiency, kg DM^{-1} ha^{-1} mm^{-1}				
7 days	29.08 A	26.63	24.40	17.41 B
14 days	15.82 B	28.37	21.06	26.89 A
28 days	15.43 B	28.02	21.70	24.22 A

In the row, average followed by different upper case differs statistically by Tukey test ($P<0.05$). ETc = culture evapotranspiration.

applied can be reduced, increasing its efficiency (Table 3). This result can be seen in table 3, the increase in water depth reduced linearly the WUE for all irrigation frequency evaluated.

The irrigation interval of 7 days promoted lower plant dry mass compared to 14 days, when it was applied 25% ETc and compared to 28 days applying 75% ETc. However, applying 50% ETc, the irrigation frequency of 7 days provided greater plant dry mass in relation to 28 days. The most frequent irrigation interval (7 days) also promoted lower first order cladode dry mass compared to 14 and 28 days (Table 3), which may be associated with the water deficit or excess promote stomatal closure, as they become stressors factors, reducing CO_2 absorption and photoassimilates production as sugars and organic acids, influencing the plant development (SILVA et al., 2015; TAIZ et al., 2017).

This negative factor of the lack or excess of water for the plant is also observed that increasing water depth promoted a quadratic response in plant dry mass and in first order cladode dry mass, respectively for intermediate (14 days) and longest irrigation intervals (28 days), respectively

Table 3 - Plant dry mass, first order cladode dry mass and water use efficiency of spineless cactus Orelha de Elefante Mexicana in different irrigation frequency.

Irrigation frequency	Equation	R^2
Plant dry mass, kg		
7 days	0.398	-
14 days	$y = -7E\text{-}05x^2 + 0.009x + 0.18$	0.68
28 days	0.417	-
First order cladode dry mass, kg		
7 days	0.169	-
14 days	0.214	-
28 days	$y = 2E\text{-}05x^2 – 0.001x + 0.1988$	0.90
Water use efficiency, kg DM^{-1} ha^{-1} mm^{-1}		
7 days	$y = -0.149x + 33.699$	0.92
14 days	$y = -0.1739x + 33.904$	0.95
28 days	$y = -0.1611x + 32.412$	0.97

(Table 3). Greater plant dry mass (0.47 kg) was observed applying 64% ETc and higher first order cladode dry mass (0.19 kg) was found with 25% ETc.

Plant width and plant height increased linearly with greater water depths (Table 2). CASTRO et al. (2020) also observed an increase in plant height for Miúda and Gigante genotypes increasing water depth in the supplemental irrigation, reporting 29.26% ETo promoted maximum plant height at 360 days after planting.

Water depths or irrigation frequency did not affect the number of cladodes and cladode width in plant and per order. On average, total number of cladodes in plant and per order (first, second and third orders) was 11.20; 4.3; 5.8 and 0.1, respectively. Cladode width was on average, 19.0; 20.8; 18.2; 19.0 and 1.6 cm, respectively, considering the average in plant, basal cladode, and cladodes from first, second, and third orders.

Greater water depths increased and first and second orders cladode length up to 72% and 78% ETc, reaching 0.19 cm to 0.28 cm, respectively (Table 4). Cladode thickness and CAI was not influenced by water depths. The thickness of cladodes was on average 1.5 cm, considering all cladodes in plant, and 4.1; 1.5; 1.1 and 0.1 cm for basal cladode and first, second and third cladodes orders, respectively.

First order cladode dry mass increased linearly, considering the water depths (Table 4). The highest FMY (314,845 kg ha^{-1}) and DMY (23,661 kg ha^{-1}) was observed when it was applied 77% and 75% ETc, respectively, demonstrating the additional water supply by supplemental irrigation promotes structural changes on plant, especially on first cladode order, increasing plant height and width and promoting greater forage yield.

First order cladode length and cladode dry mass were lower for 7 days compared to 28 days, without difference for both compared to 14 days (Table 5). The most frequent irrigation interval (7 days) promoted 10.7% to 20.5% of soil humidity before and after irrigation, while the irrigation interval of 28 days provided 2.5% to 27.7% of soil humidity (Table 1), both strategies allow a similar productive performance.

Average cladode thickness in the plant and thickness of basal cladode were greater for 7 days compared to 28 days (average cladode thickness) and 14 or 28 days for basal cladode thickness (Table 3).

Irrigation frequency did not influence FMY and DMY. Pereira et al. (2015) also did not observe differences on growth variables for IPA Sertânia, Miúda and Orelha de Elefante Mexicana genotypes, evaluating three irrigation intervals (7, 14 and 28 days).

According to SCALISI et al. (2015) the spineless cactus is able to present growth at low hydration levels and the cladode growth is very responsive to rehydration, storing water in its parenchyma and releases to chlorenchyma to perform many physiological activities even for long irrigation frequency.

Total number of cladodes and CAI are indicative of similar plant growth considering all irrigation frequencies. CORTÁZAR & NOBEL (1991) reported the CAI represents the photosynthesis capacity of the plant and is related to the spineless cactus growth. The CAI observed in this research was 1.9, very close to the 2.0 to 2.5 considered as the values to maximize cactus yield.

Crude protein, NDF, ash and IVDMD was not influenced by water depths and irrigation frequencies, presenting 7.77%, 6.20%, 15.83%, 20.78% and 79.80% for DM, CP, ash, NDF and IVDMD, respectively, due to the similar maturity stage of cladodes.

Table 4 - Structural responses and forage yield of spineless cactus Orelha de Elefante Mexicana (*Opuntia stricta* (Haw.) Haw) in different water depths, and harvested 12 months after regrowth, in Curacá-BA.

Variable	Equation	R^2
Plant height, m	$y = 0.079x + 61.392$	0.95
Plant width, m	$y = 0.0856x + 69.984$	0.93
First order cladode length, cm	$y = -0.0008x^2 + 0.1454x + 20.565$	0.91
Second order cladode length, cm	$y = -0.0009x^2 + 0.1404x + 22.496$	0.99
FMY, kg ha^{-1}	$y = -31.625x^2 + 4904.2x + 124717$	0.98
DMY, kg ha^{-1}	$y = -2.3386x^2 + 351.5x + 10454$	0.99

Table 5 - Structural responses of spineless cactus Orelha de Elefante Mexicana (*Opuntia stricta* (Haw.) Haw) in different irrigation frequency and harvested 12 months after regrowth, in Curaçá-BA.

	----------Irrigation frequency, days----------		
Variable	7	14	28
First order cladode length, m	0.248 B	0.260 AB	0.262 A
Cladode thickness, cm	1.58 A	1.51 AB	1.44 B
Basal cladode thickness, cm	4.52 A	4.08 B	3.72 B

In the line, average followed by different upper case differs statistically by Tukey test (P<0.05).

CONCLUSION

Water depths up to 77% of crop evapotranspiration increases forage yield, and irrigation frequency from 7 to 28 days can be adopted for spineless cactus Orelha de Elefante Mexicana.

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DECLARATION OF CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest. The funding entities had no influence on the study design; nor in the collection, analysis or interpretation of the data; in the writing of the manuscript, nor in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

BIOETHICS AND BIOSSECURITY COMMITTEE APPROVAL

This research was approved by the Ethics Committee on the Use of Animals (CEUA) of Embrapa Semiárido (Protocol 10/2017).

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