ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 11, Issue, 08, pp. 49469-49476, August, 2021
https://doi.org/10.37118/ijdr.22590.08.2021

RESEARCH ARTICLE **OPEN ACCESS**

YIELD AND SURVIVAL RATE OF ‘GIGANTE’ CACTUS PEAR UNDER REGULATED DEFICIT IRRIGATION USING WASTEWATER

José Alberto Alves de Souza[1], Delfran Batista dos Santos[2], Giliarde Alves dos Reis[1], João Abel da Silva[1], Thaís Carvalho Camelo[1], Sérgio Luíz Rodrigues Donato[1] and Danielle Brito Trindade[1]

[1]Instituto Federal Baiano, Campus Guanambi, Distrito de Ceraíma - CEP: 46430-000, Bahia, Brazil
[2]Instituto Federal Baiano, Campus Serrinha, Estrada Vicinal de Aparecida, s/n, Bairro Aparecida, Serrinha - CEP: 48700-000 - Bahia, Brazil

ARTICLE INFO

ArticleHistory:
Received 20th May, 2021
Received in revised form
08th June, 2021
Accepted 17th July, 2021
Published online 29th August, 2021

Key Words:

Fertigation, Domestic Sewage, Opuntia ficus, Water use Efficiency, Semiarid.

***Corresponding author:**
Vanda Palmarella Rodrigues

ABSTRACT

This study aimed to evaluate the yield and survival rate of 'Gigante' cactus pear (*Opuntia ficus indica*) cultivated with regulated deficit irrigation (RDI) using wastewater under semiarid soil and climatic conditions. The experiment was carried out between October 2015 and August 2017 at Instituto Federal Baiano, campus Guanambi, Brazil. The treatments were as follows: no fertilization and no irrigation (T1); no fertilization and RDI with wastewater (0.6 L plant^{-1} week^{-1}) (T2); no fertilization and RDI with wastewater (1.2 L plant^{-1} week^{-1}, applied once a week) (T3); no fertilization and RDI with wastewater (1.2 L plant^{-1} week^{-1}, divided into two applications per week) (T4) with organic fertilization (60 Mg ha^{-1} of bovine manure) and RDI with common water (1.2 L plant^{-1}week^{-1}) (T5) and with organic fertilization (60 Mg ha^{-1} of bovine manure) and no irrigation (T6). The treatments were arranged in a randomized complete block design with five replicates. Based on the results, we concluded that (i) regulated deficit irrigation using wastewater increased the productivity of 'Gigante' cactus pear when compared to the rainfed crop and (ii) the application of 0.6 L plant^{-1} week^{-1} was sufficient to increase the survival rate of 'Gigante' cactus pear under prolonged drought conditions.

Citation: ***Gilberto Alves Dias, Benedito Fernandes da Silva Filho, Juliana Costa Machado, Tatiane Dias Casimiro Valença and Vanda Palmarella Rodrigues.*** “Yield and survival rate of ‘Gigante’ cactus pear under regulated deficit irrigation using wastewater*”, International Journal of Development Research*, 11, (07), 49469-49476.

INTRODUCTION

Semiarid regions are characterized by scarce and irregular rainfall, either in spatial or temporal distribution, sometimes concentrating large volumes in a short period of time, followed by long periods of drought. This variability in rainfall pattern creates difficulties in the production and availability of forage for livestock during the dry season (Correia et al., 2010). In this scenario, crops and livestock are heavily affected by prolonged periods of drought, even when the annual rainfall is close to or above the annual average, due to its irregular distribution over the year (Duarte et al., 2018). Adverse conditions limit crop production, thus making raising livestock the main source of income in this region. Water scarcity in agriculture requires practices for the rational use and reuse of water; innovations in agricultural systems need research aimed at finding alternative sources of input, thereby making agriculture feasible and boosting its development (Lemos et al., 2018).

Therefore, cactus pear emerges as an alternative because it is a xerophytic plant with physiological characteristics that allow a better use of water. This crop is well adapted to semi-arid conditions and is widely used to feed herds in the Brazilian northeastern region (Cordova-Torres et al, 2017). One of the factors limiting productivity is associated with scarcity or lack of rainfall because of either its small volume or poor distribution. This factor also decreases the survival rate of recentlyplanted cactus pear. An alternative to change this scenario would be the use of irrigation (Pereira et al., 2015). Regulated deficit irrigation (RDI) works on the premise that crops cope with a reduced water supply by reducing transpiration (stomata regulation or reducing leaf surface area through reducing leaf growth) (Wilkinson and Hartung, 2009) or closing the stomata during the day and opening them at night for CO_2 fixation, such as cactus pear. In this sense, a controlled water deficit during particular periods may benefit water productivity (WP) by increasing irrigation water savings, minimizing or eliminating negative impacts on yield and crop revenue and even improving harvest quality. Considering that good quality water is scarce in semi-arid regions and should be preferably used for domestic and human supply (Brazil, 2005), it is possible to use wastewater to increase yields and solve social and environmental problems of rural families and communities. Furthermore, wastewater is an alternative source of nutrients, such as nitrogen, potassium, phosphorus, calcium, and magnesium (Medeiros et al., 2011); thus, wastewater can replace, in whole or in part, the need for chemical or organic fertilizers. This study aimed to evaluate the yield and survival rate of the 'Gigante' cactus pear (*Opuntia ficus indica*) cultivated with regulated deficit irrigation using wastewater in the semi-arid region of Bahia state, Brazil.

MATERIAL AND METHODS

The experiment was conducted at the Federal Institute of Education, Science, and Technology Baiano, campus Guanambi, Bahia state, Brazil (14º 13' 30"S and 42º 46' 53"W). Semiarid is the predominant climate; the mean annual rainfall is 663.69 mm, the mean annual evapotranspiration (ET) rate is 1961.6 mm, and the mean temperature is 26 °C. The soil was classified as an atypical medium-textured dystrophic yellow, red Latosol (Embrapa, 1999). Physical and chemical characterizations of the soil were performed before implementing the experiment using soil samples collected at depths of 0-20 and 20-40 cm. The results from each depth were, respectively: pH (H_2O) = 5.7 and 5.3; P = 23.5 and 5.8 mg dm^{-3}; K^+ = 108.0 and 104.0 mg dm^{-3}; Na^+ = 0.1 and 0.1 $cmol_c$ dm^{-3} (Mehlich-1); Ca^{2+} = 1.4 and 1.2 $cmol_c$ dm^{-3}; Mg^{2+} = 0.6 and 0.4 $cmol_c$ dm^{-3}; Al^{3+} = 0.0 and 0.0 $cmol_c$ dm^{-3} (1 mol KCl L^{-1}); H+Al = 1.7 and 1.5 $cmol_c$ dm^{-3} (0.5 mol L^{-1} calcium acetate, pH 7.0); SB = 2.4 and 1.9 $cmol_c$ dm^{-3}; t = 2.4 and 1.9 $cmol_c$ dm^{-3}; T = 4.1 and 3.5 $cmol_c$ dm^{-3}; V = 58% and 56%; m = 0.0% and 0.0%; B = 0.3 and 0.2 mg dm^{-3}; Cu = 0.4 and 0.2 md dm^{-3}; Fe = 16.0 and 17.9 mg dm^{-3}; Mn = 32.5 and 21.8 mg dm^{-3}; Zn = 2.1 and 1.2 mg dm^{-3}; and EC = 0.7 and 0.8 dS m^{-1}. The crop used in the experiment was cactus pear (*Opuntia ficus indica*), cultivar Gigante. The experiment was carried out from October 2015 to August 2017. During this period, the main climatic parameters (wind speed, air temperature, relative humidity, net radiation and precipitation) were monitored using an automatic weather station installed near the experimental area.

The yield and survival rate of 'Gigante' cactus pear under RDI using wastewater were evaluated. The experiment was designed in randomized blocks with six treatments and five replicates. The treatments were as follows:

- T1: no fertilization and no irrigation;
- T2: no fertilization and RDI with wastewater (0.6 L plant^{-1} week^{-1});
- T3: no fertilization and RDI with wastewater (1.2 L plant^{-1} week^{-1}, applied once a week);
- T4: no fertilization and RDI with wastewater (1.2 L plant^{-1} week^{-1}, divided into two applications of 0.6 L plant^{-1} week^{-1});
- T5: with organic fertilization (60 Mg ha^{-1} of bovine manure, applied before planting) and RDI with common water (1.2 L plant^{-1} week^{-1}); and
- T6: with organic fertilization (60 Mg ha^{-1} of bovine manure applied before planting) and no irrigation.

The experimental plot consisted of three 6-m-long rows of plants spaced 1 m apart (30 plants per row, spaced 0.2 m apart), with a 30 m^2 area (6 m x 5 m - including a 3-m-wide path), with a stand of 30,000 plants ha^{-1}. In the blocks, the treatments succeeded each other without additional spacing, so only the plants within the 4-m-long central row of each plot (20 plants per row, 60 plants in total) were evaluated. The remaining plants were borders. Thus, each block was 36 m long and 2 m wide, spaced apart by a 3-m-wide path. On the outer sides, there was also a 3-m-wide path surrounding the experimental area. The area was subsoiled, plowed, harrowed and then furrowed at a distance of one meter between furrows. Bovine manure was applied only in the planting furrow of the plots of the T5 and T6 treatments (60 Mg ha^{-1}). Mature cladodes with accumulation of reserves were selected in another cactus pear plantation of the campus; after harvest, they remained in the shade for 15 days to cure. After curing, the cladodes were planted with the longest portion buried approximately 50% in the soil for better fixation at a distance of one meter between planting rows. The cladodes were spaced 20 cm apart. Weeds were mechanically controlled during the experiment. Planting was completed at the end of October 2015. The wastewater was collected from a stabilization pond that receives domestic sewage collected from campus buildings. It was stored for 24 hours in a water tank (5000 L) before using it for irrigation so that the larger particles could settle on the bottom of the tank, reducing clogging problems. The common water was collected in a tubular well installed on campus and stored in a water tank (500 L). Both irrigations, with common and wastewater, were performed using a drip irrigation system consisting of a submersible pump with a power of 450 W and an output diameter of 1"; a 200 mesh disk filter with an output diameter equal to 1"; a PVC derivation line with a nominal diameter of 32 mm; lateral lines in a low-density polyethylene dripper tube with a nominal diameter equal to 16 mm and nominal flow of emitters equal to 1.5 L h^{-1} at a pressure of 150 kPa. Emitters were spaced 0.5 m apart on the lateral line. This spacing allowed the formation of a 0.5-m-wide wet band along the planting line. This wet band represents 30% of the wet area. Irrigation began on April 18, 2016, after the end of the rainy season, and lasted until Algust 21, 2017. In treatment T2, the irrigation time was 1.0 h, once a week; in treatments T3 and T5, it was 2.0 h, once a week; and in treatment T4, it was 1.0 h, twice a week. These times, combined with the flow of the emitters and number of plants, resulted in an average weekly volume per plant equal to 0.6 L in T2; and 1.2 L in treatments T3, T4 and T5.

A wastewater sample was collected every four months, from April 2016 to August 2017, totaling five samples. The wastewater samples were integrated into an average sample and subjected to laboratory analysis to determine nutrient levels, pH, and electrical conductivity. The common water and bovine manure were also analyzed. The pH readings of wastewater (WW) and common water (CW) were 7.1 and 6.8, respectively, with electrical conductivities of 1.0 and 2.9 dS m^{-1}, respectively. The average levels of macro- and micronutrients present in WW, CW and bovine manure (BM) are presented in Table 1.

Table 1. Macro- and micronutrient levels present in wastewater (WW), common water (CW) and bovine manure (BM)

Nutrient	WW	CW	BM
	mg L^{-1}	mg L^{-1}	mg Kg^{-1}
N	7.98	-	5200
P	4.7	-	4700
K	65.6	0.31	2500
S	-	-	2300
Ca	200	6.43	1700
Mg	30	4.38	200
Cu	0.006	-	45.2
Fe	4.6	-	1932.4
Mn	0.002	-	391.8
Zn	0.002	-	200.5
Na	338.40	12.03	-

At each wastewater evaluation, the irrigation system was evaluated as well. Mean weekly water depth (Dm) and the uniformity of water distribution (DU) were evaluated at each irrigated treatment. The calculation of Dm took into account the mean flow rates (Fm) multiplied by the irrigation time of each treatment and then divided by the wet area of the emitter. The total volume of wastewater applied to each treatment was obtained by multiplying Fm by weekly irrigation time and number of weeks. This volume multiplied by the wastewater nutrient contents resulted in the contribution of nutrients for the plants in T2, T3, and T4. Precipitation and reference evapotranspiration (ETo) data, obtained from an automatic weather station installed on campus, and Dm were used to perform the crop water balance (CWB), according to the method proposed by Thornthwaite and Mather (1955).

CWB was used for the whole experimental period to determine the water deficit of the crop in all treatments. The CWB was set up using Dm applied on all irrigated days to obtain the total irrigation (I) in the irrigated treatments. For this, the crop coefficient (Kc) was considered to be 0.5, according to Consoli, Inglese and Inglese (2013). The total soil water storage capacity (TWSC) was 50.4 mm, calculated on the basis of the field capacity (FC = 15%), permanent wilting point (PWP = 6%), soil global density (Dg = 1.4), and rooting depth (Z = 40 cm). Crop vegetative characteristics were evaluated five times: at 280 and 365 days after planting (DAP) (in the middle and at the end of the first dry period, respectively); 490 DAP (at the end of second rainy season); 580 and 640 DAP (in the middle and at the end of second dry period, respectively). The evaluated vegetative characteristics were plant height (PH), number of cladodes (NOC), cladode length (CL), cladode width (CW), cladode area (CA), and cladode area index (CAI). Additionally, the number of dead plants (NDP) was determined.

Measurements were taken in six (6) plants randomly selected from each evaluation unit, which contained a total of 60 plants. The PH, CL and CW were determined using a measuring tape. NOC was determined by counting all cladodes on the mother plant. To measure the height of the plant, the distance from the ground to the tip of the highest cladode was considered. The length and width of the cladodes were determined using the longest straight line across the cladode. All cladodes of evaluated plants were measured. The cladode area was determined using the methodology described by Pinto et al. (2002), according to Equation 1.

$$CA = CL\ CW\ 0.693$$

where:
CA = cladode área, cm^2;
CL = cladode length, cm;
CW = cladode width, cm; and

0.693 is the correction factor due to the ellipsoidal shape of the cladode. Subsequently, the CA was multiplied by NOC and then by two, since both sides of the cladode should be considered, to obtain the total area of the cladodes (TAC), in cm^2. TAC was converted to m^2 by dividing it by 10,000. The CAI was obtained by dividing TAC (m^2) by the area occupied by the plant on the soil (m^2), thus determining the photosynthetically active area of the plant (TAC, m^2) per soil area (m^2). NDP was determined by counting all the plants in no conditions of reestablishing their physical structures. To determine green matter yield (GMY, in Mg ha^{-1}), all 60 plants of the evaluation unit of each plot were harvested and weighed. The GMY was determined by multiplying the total mass of each evaluation unit (Mg evaluation unit^{-1}) by 10,000 m^2 ha^{-1} and dividing by 20 m^2 evaluation unit^{-1}, in other words, multiplying the total mass of each plot by 500.
To determine dry matter yield (DMY, in Mg ha^{-1}), thirty cladode samples per treatment were collected using a hole saw (5.00 cm in diameter by 4.00 cm deep) coupled to a battery powered drill. The total mass of thirty samples taken in each treatment ranged from 1,500 to 2,000 g. The samples were dried in a forced-air oven at 60 ºC for 72 h. Dry matter content, in percentage (DM%), was determined as described by Silva & Queiroz (2009). DMY was calculated according to Equation 2.

$$DMY = \frac{GMY\ DM\%}{100} \qquad (2)$$

The data obtained were subjected to the Shapiro-Wilk normality test and Bartlett homoscedasticity test. One-way analysis of variance was performed. The means were grouped using the Scott-Knott test. A significance level of 5% was used for all analyzed variables, except for DMY, for which a significance level of 10% was used to meet the production dynamics, as the factors that may influence crop development are diverse and uncontrollable. This allowed the occurrence of type II errors due to greater statistical rigor of the test in identifying significant differences between treatments (Ferreira, 2011). Statistical analyses were performed using the statistical program "Sisvar" (Ferreira, 2014).

RESULTS

Water Distribution Uniformity: the mean flow rates of drippers, distribution uniformity, coefficient of variation of flow, and mean weekly water depth applied to each irrigated treatment after five evaluations of the irrigation system are shown in table 2.

Table 2. Mean flow rates of the drippers (q_m), distribution uniformity (DU), coefficient of variation of flow (CV_q), and mean weekly water depth (D_m) applied to each irrigated treatment

Treatment	q_m (L h^{-1})	DU (%)	D_m (mm)	CV_q (%)
T2	1.495	95	5.98	5.29
T3	1.441	94	11.53	5.19
T4	1.443	94	11.53	7.66
T5	1.470	93	11.76	6.84

T2: without fertilization and RDI with wastewater (0.6 L plant^{-1}week^{-1}); T3: without fertilization and RDI with wastewater (1.2 L plant^{-1}week^{-1}); T4: without fertilization and RDI with wastewater (0.6 L plant^{-1}, two applications per week); T5: with bovine manure (60 Mg ha^{-1}) and RDI with common water (1.2 L plant^{-1} week^{-1}).

Table 2 shows that the CVq ranged from 5.19 to 6.84, values below 10%, meeting the limits established by ASAE (1996).

Crop Water Balance (CWB): monthly precipitation and potential crop evapotranspiration (etpc) during the experiment are depicted in Figure 1.

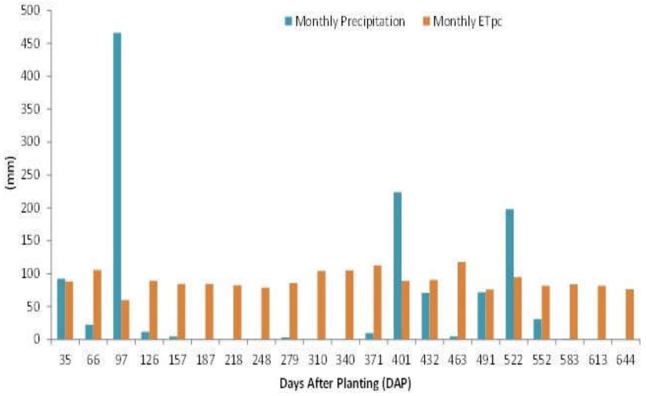


Figure 1. Monthly precipitation and potential crop evapotranspiration (monthlyETpc) from November 2015 (from 6 to 35 DAP) until August 2017 (from 614 to 644 DAP)

Figure 1 shows the long duration of two dry seasons: the first from 126 to 371 DAP and the second from 552 DAP to harvest. Table 3 summarizes the CWBs in all treatments for the period from the third week of january 2016, the last period in which the soil was in field capacity (twsc equal to 50.4 mm) in all treatments, to the fourth week of august 2017, when the crop was last irrigated.

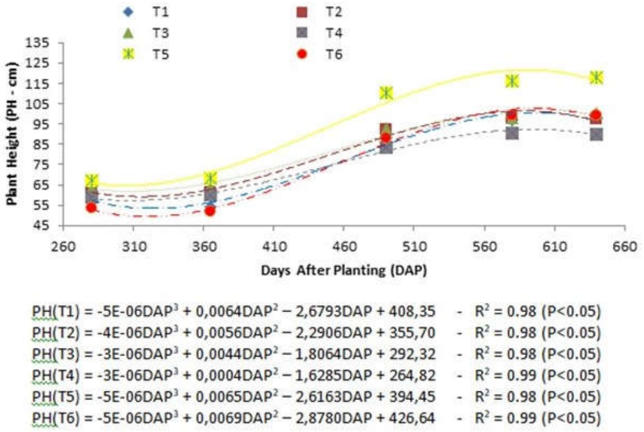
Plant Height (PH): Representative models of the evolution of mean plant height over time (280 to 640 DAP) and their respective regression equations are shown in Figure 2. The best fits were obtained with third-degree polynomial equations ($P < 0.05$). The fitted models are justified by the occurrence of two dry periods, with pronounced water deficit and decreased plant growth, a rainy period in between, with increased plant growth.

Number of cladodes (NOC): Figure 3 presents the representative models of the evolution of the average number of cladodes over time (280 to 640 DAP) and their respective regression equations. Again, the best fits were obtained with third degree polynomial equations ($P < 0.05$). The fitted models are justified for the same reasons observed for plant height. There was only a significant difference for NOC as a function of time in treatments T5 and T6.

Table 3. Summary of the crop water balance (CWB) in all treatments from the third week of January 2016 until the fourth week of August 2017

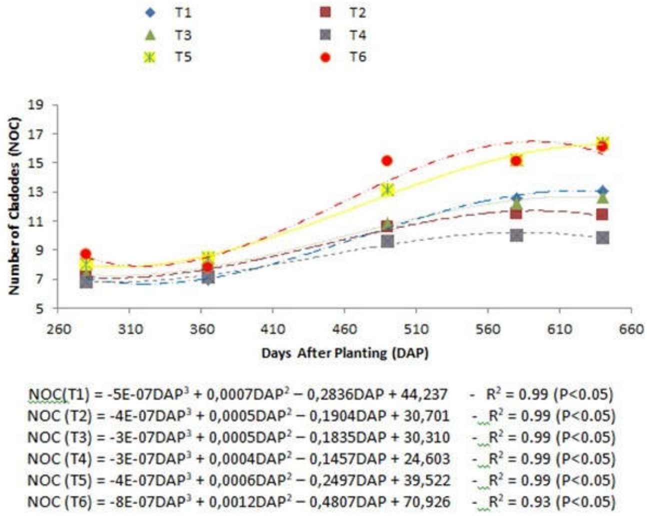
Treatment	ETo (mm)	Kc	ETpc (mm)	P (mm)	I+P-ETpc (mm)	ETc (mm)	DEF (mm)	EXC (mm)	I (mm)	ETc/ ET_{pc}
T1	3433.30	0.50	1716.65	923.52	-793.13	455.65	-1261.01	567.75	0.00	0.27
T2	3433.30	0.50	1716.65	923.52	-923.52	769.80	-946.85	586.60	382.72	0.45
T3	3433.30	0.50	1716.65	923.52	-55.00	1146.37	-570.28	613.01	738.13	0.67
T4	3433.30	0.50	1716.65	923.52	-55.00	1146.37	-570.28	613.01	738.13	0.67
T5	3433.30	0.50	1716.65	923.52	-40.49	1110.00	-606.66	614.19	752.64	0.65
T6	3433.30	0.50	1716.65	923.52	-793.13	455.65	-1261.01	567.75	0.00	0.27

T1: no fertilization and noirrigation; T2: no fertilization and RDI with wastewater (0.6 L plant-1week-1); T3: no fertilization and RDI with wastewater (1.2 L plant-1week-1); T4: no fertilization and RDI with wastewater (0.6 L plant-1, two applications per week); T5: with organic fertilization (60 Mg ha-1) and RDI with common water (1.2 L plant-1 week-1); T6: noirrigation and with organic fertilization (60 Mg ha-1). ETo: reference evapotranspiration; Kc: crop coefficient; ETpc: potential crop evapotranspiration; P: rainfall; ETc: real crop evapotranspiration; DEF: deficit; EXC: excess; I: irrigation; ETc/ ETpc: relative crop evapotranspiration.



$PH(T1) = -5E\text{-}06DAP^3 + 0{,}0064DAP^2 - 2{,}6793DAP + 408{,}35$ - $R^2 = 0.98$ (P<0.05)
$PH(T2) = -4E\text{-}06DAP^3 + 0{,}0056DAP^2 - 2{,}2906DAP + 355{,}70$ - $R^2 = 0.98$ (P<0.05)
$PH(T3) = -3E\text{-}06DAP^3 + 0{,}0044DAP^2 - 1{,}8064DAP + 292{,}32$ - $R^2 = 0.98$ (P<0.05)
$PH(T4) = -3E\text{-}06DAP^3 + 0{,}0004DAP^2 - 1{,}6285DAP + 264{,}82$ - $R^2 = 0.99$ (P<0.05)
$PH(T5) = -5E\text{-}06DAP^3 + 0{,}0065DAP^2 - 2{,}6163DAP + 394{,}45$ - $R^2 = 0.98$ (P<0.05)
$PH(T6) = -5E\text{-}06DAP^3 + 0{,}0069DAP^2 - 2{,}8780DAP + 426{,}64$ - $R^2 = 0.99$ (P<0.05)

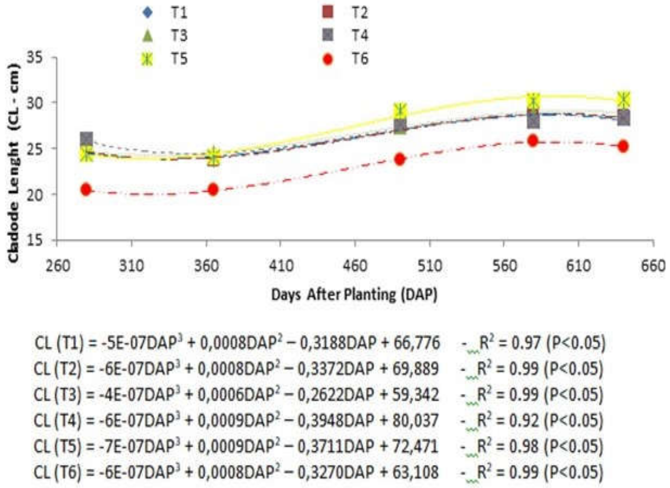
Figure 2. Mean plant height from 280 to 640 DAP and their respective regression equations for treatments T1: no fertilization and no irrigation; T2: no fertilization and RDI with wastewater (0.6 L plant^{-1} week^{-1}); T3: no fertilization and RDI with wastewater (1.2 L plant^{-1} week^{-1}); T4: no fertilization and RDI with wastewater (0.6 L plant^{-1}, two applications per week); T5: with organic fertilization (60 Mg ha^{-1}) and RDI with common water (1.2 L plant^{-1} week^{-1}); T6: no irrigation and with organic fertilization (60 Mg ha^{-1})



$NOC(T1) = -5E\text{-}07DAP^3 + 0{,}0007DAP^2 - 0{,}2836DAP + 44{,}237$ - $R^2 = 0.99$ (P<0.05)
$NOC(T2) = -4E\text{-}07DAP^3 + 0{,}0005DAP^2 - 0{,}1904DAP + 30{,}701$ - $R^2 = 0.99$ (P<0.05)
$NOC(T3) = -3E\text{-}07DAP^3 + 0{,}0005DAP^2 - 0{,}1835DAP + 30{,}310$ - $R^2 = 0.99$ (P<0.05)
$NOC(T4) = -3E\text{-}07DAP^3 + 0{,}0004DAP^2 - 0{,}1457DAP + 24{,}603$ - $R^2 = 0.99$ (P<0.05)
$NOC(T5) = -4E\text{-}07DAP^3 + 0{,}0006DAP^2 - 0{,}2497DAP + 39{,}522$ - $R^2 = 0.99$ (P<0.05)
$NOC(T6) = -8E\text{-}07DAP^3 + 0{,}0012DAP^2 - 0{,}4807DAP + 70{,}926$ - $R^2 = 0.93$ (P<0.05)

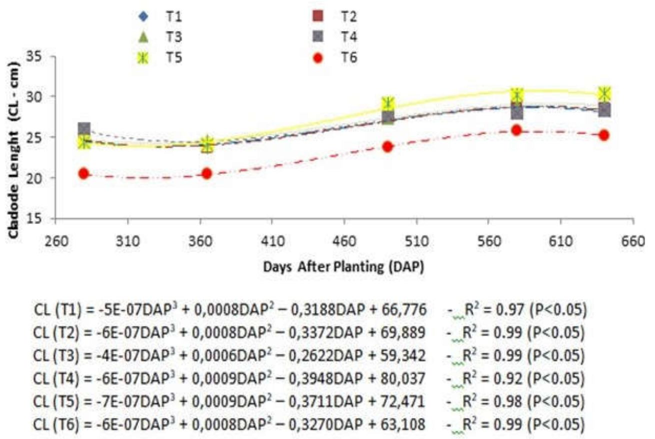
Figure 3. Mean number of cladodes from 280 to 640 DAP and their respective regression equations in treatments T1: no fertilization and no irrigation; T2: no fertilization and RDI with wastewater (0.6 L plant^{-1} week^{-1}); T3: no fertilization and RDI with wastewater (1.2 L plant^{-1} week^{-1}); T4: no fertilization and RDI with wastewater (0.6 L plant^{-1}, two applications per week); T5: with organic fertilization (60 Mg ha^{-1}) and RDI with common water (1.2 L plant^{-1} week^{-1}); T6: no irrigation and with organic fertilization (60 Mg ha^{-1})

Length and Width of Cladodes: Representative models of the evolution of the mean length and width of cladodes over time (280 to 640 DAP) are shown in Figures 4 and 5, respectively.



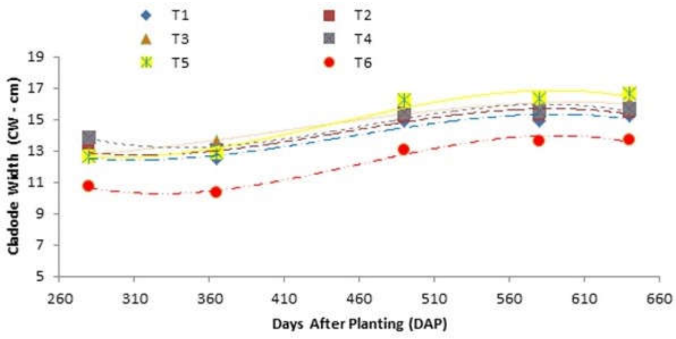
$CL(T1) = -5E\text{-}07DAP^3 + 0{,}0008DAP^2 - 0{,}3188DAP + 66{,}776$ - $R^2 = 0.97$ (P<0.05)
$CL(T2) = -6E\text{-}07DAP^3 + 0{,}0008DAP^2 - 0{,}3372DAP + 69{,}889$ - $R^2 = 0.99$ (P<0.05)
$CL(T3) = -4E\text{-}07DAP^3 + 0{,}0006DAP^2 - 0{,}2622DAP + 59{,}342$ - $R^2 = 0.99$ (P<0.05)
$CL(T4) = -6E\text{-}07DAP^3 + 0{,}0009DAP^2 - 0{,}3948DAP + 80{,}037$ - $R^2 = 0.92$ (P<0.05)
$CL(T5) = -7E\text{-}07DAP^3 + 0{,}0009DAP^2 - 0{,}3711DAP + 72{,}471$ - $R^2 = 0.98$ (P<0.05)
$CL(T6) = -6E\text{-}07DAP^3 + 0{,}0008DAP^2 - 0{,}3270DAP + 63{,}108$ - $R^2 = 0.99$ (P<0.05)

Figure 3. Mean number of cladodes from 280 to 640 DAP and their respective regression equations in treatments T1: no fertilization and no irrigation; T2: no fertilization and RDI with wastewater (0.6 L plant^{-1} week^{-1}); T3: no fertilization and RDI with wastewater (1.2 L plant^{-1} week^{-1}); T4: no fertilization and RDI with wastewater (0.6 L plant^{-1}, two applications per week); T5: with organic fertilization (60 Mg ha^{-1}) and RDI with common water (1.2 L plant^{-1} week^{-1}); T6: no irrigation and with organic fertilization (60 Mg ha^{-1})



$CL(T1) = -5E\text{-}07DAP^3 + 0{,}0008DAP^2 - 0{,}3188DAP + 66{,}776$ - $R^2 = 0.97$ (P<0.05)
$CL(T2) = -6E\text{-}07DAP^3 + 0{,}0008DAP^2 - 0{,}3372DAP + 69{,}889$ - $R^2 = 0.99$ (P<0.05)
$CL(T3) = -4E\text{-}07DAP^3 + 0{,}0006DAP^2 - 0{,}2622DAP + 59{,}342$ - $R^2 = 0.99$ (P<0.05)
$CL(T4) = -6E\text{-}07DAP^3 + 0{,}0009DAP^2 - 0{,}3948DAP + 80{,}037$ - $R^2 = 0.92$ (P<0.05)
$CL(T5) = -7E\text{-}07DAP^3 + 0{,}0009DAP^2 - 0{,}3711DAP + 72{,}471$ - $R^2 = 0.98$ (P<0.05)
$CL(T6) = -6E\text{-}07DAP^3 + 0{,}0008DAP^2 - 0{,}3270DAP + 63{,}108$ - $R^2 = 0.99$ (P<0.05)

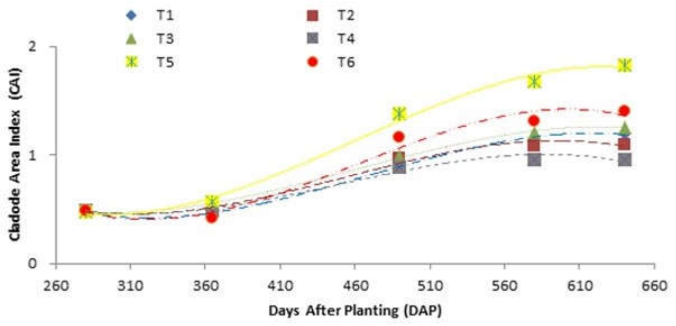
Figure 4. Mean cladode length from 280 to 640 DAP and their respective regression equations in treatments T1: no fertilization and no irrigation; T2: no fertilization and RDI with wastewater (0.6 L plant^{-1} week^{-1}); T3: no fertilization and RDI with wastewater (1.2 L plant^{-1} week^{-1}); T4: no fertilization and RDI with wastewater (0.6 L plant^{-1}, two applications per week); T5: with organic fertilization (60 Mg ha^{-1}) and RDI with common water (1.2 L plant^{-1} week^{-1}); T6: no irrigation and with organic fertilization (60 Mg ha^{-1}).



$CW (T1) = -3E\text{-}07DAP^3 + 0{,}0004DAP^2 - 0{,}1442DAP + 30{,}849$ - $R^2 = 0.95$ ($P<0.05$)
$CW (T2) = -3E\text{-}07DAP^3 + 0{,}0004DAP^2 - 0{,}1579DAP + 33{,}087$ - $R^2 = 0.95$ ($P<0.05$)
$CW (T3) = -1E\text{-}07DAP^3 + 0{,}0002DAP^2 - 0{,}0482DAP + 17{,}136$ - $R^2 = 0.99$ ($P<0.05$)
$CW (T4) = -4E\text{-}07DAP^3 + 0{,}0005DAP^2 - 0{,}2240DAP + 43{,}935$ - $R^2 = 0.92$ ($P<0.05$)
$CW (T5) = -3E\text{-}07DAP^3 + 0{,}0004DAP^2 - 0{,}1705DAP + 33{,}398$ - $R^2 = 0.96$ ($P<0.05$)
$CW (T6) = -4E\text{-}07DAP^3 + 0{,}0006DAP^2 - 0{,}2333DAP + 41{,}390$ - $R^2 = 0.98$ ($P<0.05$)

Figure 5. Mean cladode width from 280 to 640 DAP and their respective regression equations in treatments T1: no fertilization and no irrigation; T2: no fertilization and RDI with wastewater (0.6 L plant^{-1} week^{-1}); T3: no fertilization and RDI with wastewater (1.2 L plant^{-1} week^{-1}); T4: no fertilization and RDI with wastewater (0.6 L plant^{-1}, two applications per week); T5: with organic fertilization (60 Mg ha^{-1}) and RDI with common water (1.2 L plant^{-1} week^{-1}); T6: no irrigation and with organic fertilization (60 Mg ha^{-1})

Observing the growth models fitted to cladode length and width as a function of DAP (Figures 4 and 5, respectively), it appears that the increase in cladode length and width occurred slowly and proportionally, speeding up in the rainy season. Hence, again, the best fits were obtained with third degree polynomial equations ($P <0.05$). Both the mean length and mean width of cladodes in T6 were lower than in all other treatments, which did not differ statistically throughout the experiment (280 to 640 DAP).



$CAI (T1) = -6E\text{-}08DAP^3 + 8E\text{-}05DAP^2 - 0.0352DAP + 5.0870$ - $R^2 = 0.99$ ($P<0.05$)
$CAI (T2) = -6E\text{-}08DAP^3 + 8E\text{-}05DAP^2 - 0.0331DAP + 4.7180$ - $R^2 = 0.99$ ($P<0.05$)
$CAI (T3) = -5E\text{-}08DAP^3 + 6E\text{-}05DAP^2 - 0.0254DAP + 3.6379$ - $R^2 = 0.99$ ($P<0.05$)
$CAI (T4) = -5E\text{-}08DAP^3 + 7E\text{-}05DAP^2 - 0.0292DAP + 4.2195$ - $R^2 = 0.98$ ($P<0.05$)
$CAI (T5) = -9E\text{-}08DAP^3 + 0.0001DAP^2 - 0.0526DAP + 7.3472$ - $R^2 = 0.97$ ($P<0.05$)
$CAI (T6) = -8E\text{-}08DAP^3 + 0.0001DAP^2 - 0.0421DAP + 5.6878$ - $R^2 = 0.99$ ($P<0.05$)

Figure 6. Mean cladode area index from 280 to 640 DAP and their respective regression equations for the treatments T1: no fertilization and no irrigation; T2: no fertilization and RDI with wastewater (0.6 L plant^{-1} week^{-1}); T3: no fertilization and RDI with wastewater (1.2 L plant^{-1} week^{-1}); T4: no fertilization and RDI with wastewater (0.6 L plant^{-1}, two applications per week); T5: with organic fertilization (60 Mg ha^{-1}) and RDI with common water (1.2 L plant^{-1} week^{-1}); T6: no irrigation and with organic fertilization (60 Mg ha^{-1}).

Cladode Area Index (CAI): Figure 6 presents the representative models of the evolution of the mean cladode area index (280 to 640 DAP) and their respective regression equations. Again, the best fits were obtained with third degree polynomial equations ($P<0.05$). The models were fitted for the same reasons as the aforementioned traits. The models fitted to the cladode area index as a function of DAP (Figure 6) have a behavior akin to that of cladode length and width.

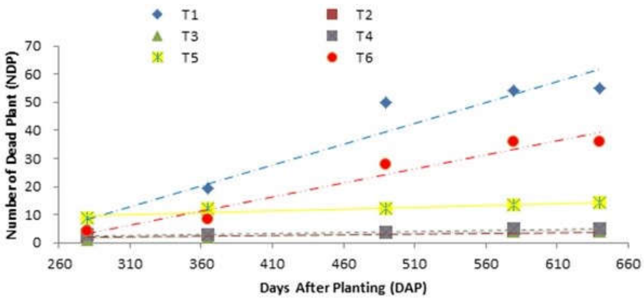
Table 4. Means of the number of dead 'Gigante' cactus pear plants cultivated without irrigation, with application of wastewater, and with application of common water

Treatments	Number of Dead Plants				
	280 DAP	365 DAP	490 DAP	580 DAP	640 DAP
T1	4.8 A	19.6 B	50.0 C	54.2 C	55.0 C
T2	2.2 A	2.4A	3.4 A	3.6A	3.6 A
T3	1.4 A	2.2A	3.8 A	4.2A	4.2 A
T4	2.8 A	3.0A	3.6 A	4.8A	4.8 A
T5	9.0 A	12.2 B	12.2 A	13.6 A	14.2 A
T6	4.2 A	8.4A	28.0 B	35.8 B	35.8 B

It appears that the growth of the cladode area index (CAI) occurred slowly and proportionally, with an acceleration in the rainy season; hence, the best fits were obtained with third degree polynomial equations ($P <0.05$).

Number of Dead Plants (NDP): Means of the number of dead 'Gigante' cactus pear plants are shown in Table 4. Observing the analysis of variance, there was a significant difference ($P <0.05$) for the treatments and periods and their interaction.

Figure 7 presents the representative models of the evolution of the mean number of dead plants (280 to 640 DAP) and their respective regression equations. In this case, the best fits were obtained with linear regressions ($P <0.05$).



$NDP (T1) = 0.1486DAP - 33.294$ - $R^2 = 0.99$ ($P<0.05$)
$NDP (T2) = 0.0084DAP - 0.7732$ - $R^2 = 0.94$ ($P<0.05$)
$NDP (T3) = 0.0044DAP + 0.9606$ - $R^2 = 0.92$ ($P<0.05$)
$NDP (T4) = 0.0062DAP + 0.8735$ - $R^2 = 0.93$ ($P<0.05$)
$NDP (T5) = 0.0124DAP + 6.3775$ - $R^2 = 0.85$ ($P<0.05$)
$NDP (T6) = 0.0993DAP - 24.340$ - $R^2 = 0.99$ ($P<0.05$)

Figure 7. Mean number of dead plants from 280 to 640 DAP and their regression equations in treatments T1: no fertilization and no irrigation; T2: no fertilization and RDI with wastewater (0.6 L plant^{-1} week^{-1}); T3: no fertilization and RDI with wastewater (1.2 L plant^{-1} week^{-1}); T4: no fertilization and RDI with wastewater (0.6 L plant^{-1}, two applications per week); T5: with organic fertilization (60 Mg ha^{-1}) and RDI with common water (1.2 L plant^{-1} week^{-1}); T6: no irrigation and with organic fertilization (60 Mg ha^{-1})

Table 4 shows that although there was no significant difference between treatments ($P> 0.05$) at 280 DAP, there was a growing mortality in non-irrigated treatments until the last period (640 DAP), while in non-irrigated treatments, there was no significantdifference between the periods. Mortality was higher in T1 (no irrigation and no fertilization), followed by T6 (no irrigation with fertilization). The plants of the irrigated treatments showed no significant difference from one another for this variable.

Green and Dry Matter Yield: Mean values of green matter yield (GMY), dry matter content (DM%) and dry matter yield (DMY) of 'Gigante' cactus pear plants cultivated without irrigation, irrigation with wastewater application, and irrigation with common water are presented in Table 5.

Table 5. Mean values of green matter yield (GMY), dry matter content (DM%) and dry matter yield (DMY) of 'Gigante' cactus pear plants cultivated without irrigation, irrigation with wastewater application and irrigation with common water

Treatments	Evaluated traits		
	GMY (Mg ha^{-1})	DM %	DMY (Mg ha^{-1})
T1	91.35 A	11.98 B	11.05 A
T2	179.00 B	7.77 A	13.82 B
T3	186.55 B	6.98 A	13.17 B
T4	171.45 B	7.13 A	12.24 B
T5	259.45 C	6.75 A	17.47 C
T6	104.85 A	10.92 B	11.38 A

Means followed by the same letter do not differ significantly from each other by the Scott-Knott test (P=0.05) for GMY and DM%; and (P=0.1) for DMY. T1: no fertilization and no irrigation; T2: no fertilization and RDI with wastewater (0.6 L planta^{1}week^{1}); T3: no fertilization and RDI with wastewater (1.2 L plant^{-1}week^{-1}); T4: no fertilization and RDI with wastewater (0.6 L plant^{-1}, two applications per week); T5: with organic fertilization (60 Mg ha^{-1}) and RDI with common water (1.2 L plant^{-1} week^{-1}); T6: no irrigation and with organic fertilization (60 Mg ha^{-1}).

Table 5 shows that the GMY in T5 (with organic fertilization and RDI with common water) was higher than that in the other treatments (P <0.05). In T2, T3 and T4 (no fertilization and RDI with wastewater), means were statistically equal to one another (P> 0.05) and were higher than those of treatments T1 and T6 (no irrigation), which also did not differ from each other (P> 0.05). The DMY in T1 (Table 5) was higher than in other treatments (P <0.1); treatments T1 and T6 did not differ from each other (P> 0.1) and were inferior to treatments T2, T3 and T4, which did not differ from each other either (P> 0.1). Table 5 shows that treatment T5, which received organic fertilization with 60 Mg ha^{-1} of bovine manure and was irrigated with common water, had the highest yields (GMY and DMY). This treatment was followed by treatments T2, T3, and T4, all without organic fertilization and irrigated with wastewater. These were superior to treatments T1 and T6, which were non-irrigated, with and without organic fertilization, whose yields were statistically equal.

Dry matter contents (Table 5) in the irrigated treatments (T2, T3, T4, and T5), which did not differ from each other (P> 0.05), were lower than in the treatments without irrigation (T1 and T6), which did not differ from each other either (P> 0.05).

DISCUSSION

Water Distribution Uniformity: The uniformity of water distribution, with DU ranging from 93 to 95%, can be considered excellent in all treatments, according to the evaluation criterion proposed by Mantovani (2001) (Excellent: DU>90%). It was observed that the use of wastewater during the whole experiment had no negative effect on the uniformity of the water distribution or on the average flow of emitters. The flow rate of emitters was close to the nominal flow reported by the manufacturer (1.5 L h^{-1}) in all treatments. Macan et al. (2017), in studies conducted with dairy effluents treated by biological processes, found DU values greater than 96%. However, over time, these values decreased. Nascimento et al. (2017) affirm that irrigation systems with low uniformity of water distribution over-irrigate part of the cultivated area while under-irrigating others, thus reducing water availability to crops; as a consequence, production cost increases. The determination of DU is important because it allows a more rigorous evaluation of the irrigation system and the adoption of measures aimed at maintaining high uniformity of water distribution, reducing the negative impact that lower irrigation levels may exert on plants.

Crop Water Balance (CWB): Table 3 shows that even for the crop with a low water demand (Kc=0.5), in the non-irrigated treatments (T1 and T6), the water deficit was equal to 73% [(1 - ETc/ETpc).100]. This means that the crop has failed to transpire a potential amount that is almost three times greater than what it had actually transpired. If we take into account a production function relating real yield and potential yield (1 - Yr/Yp) proportional to transpiration, the crop lost approximately three-quarters of its productive potential. On the other hand, in the treatment with organic fertilization and water supplementation with common water (1.2 L week^{-1} plant^{-1}) (T5), the water deficit was 35%, that is, the crop had not transpired just over a third of its potential evapotranspiration. Evapotranspiration is directly linked to plant production, since water deficit has a direct effect on crop production. The water lost through evapotranspiration is responsible for various processes within plant cells, as well as being responsible for transporting nutrients available in the soil.

Plant Height (PH): The first two assessments (280 and 365 DAP) were made in the middle and at the end of the first dry period; the third assessment (490 DAP) was made in the middle of the second rainy season; and the last two assessments (580 and 640 DAP) were made in the middle and at the end of the second dry period. Between the second (365 DAP) and third (490 DAP) assessments, most of the annual precipitation had already occurred, as shown in Figure 1(408 mm). The rainy period occurred in the intermediate phase of the research, creating conditions for a faster growth rate, which can be verified in all treatments. During the rainy season (between the second and third assessments), the mean plant height in all treatments increased considerably, in contrast to the two dry periods, during which plant height increased slowly. The fitted third-degree models clearly show this behavior. The increase in water availability during the rainy season shows that the plant has satisfactory results under more favorable conditions, resulting in growth.

Number of cladodes (NOC): Although there was a significant difference only for NOC over time in treatments T5 and T6, it is clear that there was an increasing trend of NOC over time in all treatments. Ramos et al. (2015) similarly found a linear increase in the total number of cladodes over time because, according to them, as the plant grows, there is an increase in the number of cladodes. According to Queiroz et al. (2015), the cactus pear responds more quickly to the emission of first- and second-order cladodes when irrigated, showing that efficient water use by the plant is reflected in increased growth and development.

Length and Width of the Cladodes: Considering that there was no application of water in treatments T1 and T6, it was supposed that the average length and width of the cladodes in these treatments were lower than in the other treatments, which received irrigation. Observing the average number of cladodes (Figure 3), we observed that in treatments T5 and T6, both fertilized means were higher than in the other treatments. Higher cladode sprouting negatively affected the mean length and width of cladodes in the T6 treatment when compared to that in T1, both of which were not irrigated. In T5, even with a higher number of cladodes, sprouting had no interfere with the mean cladode length and width, probably because the plants of this treatment were both irrigated and organically fertilized. According to Lemos et al. (2018), the increase in cladode length always occurs in the first months. Although the plant is under favorable conditions during its development, it does not influence cladode length; the author also reports that the average length of cladodes is directly related to the availability of water and nutrients and the absorption of light energy used by the plant for photosynthesis, which is affected by spacing and planting density. Azevedo Junior (2017), studying wastewater on cactus pear performance, observed that cladode length and width increased linearly, showing a direct relationship between width and length cladode with respect to growth rate. The cactus pear has a similar growth of cladodes, with longitudinal and perpendicular elongation of cladodes and cladode sprouting tending to grow slower over time.

Cladode Area Index (CAI): The results were as expected since the CAI response rate is dependent on morphological characteristics such as cladode number, cladode length and width. The CAI is directly linked to the favorable conditions that contribute to the development of the plant. From 365 DAP (Figure 6), the T5 plants showed higher CAI than the plants of the other treatments. In addition, the T6 treatment plants had higher CAI than the other treatment plants from

580 DAP. According to Fonseca et al. (2019), an important physiological characteristic is the cladode area index, since the higher the CAI is, the larger the area for the absorption of photosynthetically active radiation and, consequently, the greater the crop yield. Among the factors that affect the CAI, the nutritional status of the plant stands out. Donato et al. (2014) pointed out that the CAI is a factor that determines the active photosynthetic area of the plant since it indicates the plant's ability to intercept sunlight to efficiently transform it into dry matter production. Padilha Junior (2016), in studies with planting density and fertilization, reported that the best CAIs resulted from fertilization, with rates above 30 Mg ha^{-1}; CAI was not influenced by planting density. However, the higher CAI does not always imply higher productivity, since in the present work, in the calculation of the CAI, the area occupied by the plant in the soil was calculated considering the planting stand (30,000 plants ha^{-1}). However, throughout the experiment, there was different plant mortality across treatments, which influenced overall productivity.

Number of Dead Plants (NDP): Analyzing Table 4 and Figure 7, it can be seen that the number of dead plants in non-irrigated treatments tends to increase linearly, while in irrigated treatments, this mortality remains almost constant. Thus, it is evident that irrigation was fundamental for plant survival in these treatments. Considering that 'Gigante' cactus pear is a perennial plant that, if well managed, can produce for over 50 years (Dubex Junior., 2017), it is expected that the crop will undergo many periods of prolonged drought throughout its life cycle, which could compromise the plant stand with increasing mortality in non-irrigated treatments. Thus, in addition to ensuring higher productivity, irrigation, even with controlled deficits, as was the case in this work, can guarantee productivity throughout the crop's useful life. Table 4 shows that at 640 DAP, the average plant mortality in the non-irrigated treatments T1 and T6 was 55 and 36 dead plants, respectively, in a population of 90 plants in each treatment plot, which represents, on average, 61% and 40% mortality rates, respectively. In the treatments irrigated with wastewater, T2, T3, and T4, the number of dead plants represented, on average, a mortality rate ranging from 4% to 6%; in treatment T5, irrigated with common water and fertilized, the mortality rate was, on average, 16%;this rate was much lower than that of non-irrigated treatments but higher than that in the treatments irrigated with wastewater. Among the non-irrigated treatments, plant mortality at 640 DAP was 35% higher in the non-fertilized treatment. Thus, it can be inferred from these results that organic fertilization contributed to better water retention by the plant, which further contributed to the reduction in mortality rate. The cactus pear has a high resilience capacity and can respond quickly when subjected to favorable conditions. For several months, the crop was subjected to a combination of drought and high potential crop evapotranspiration (Figure 1), which caused the crop to lose its resilience, leading several plants to die.

Green and Dry Matter Yield: The results obtained for green and dry matter yield were corroborated by studies already published by other researchers. Lima et al. (2015) state that irrigation applied to smaller depths favors the transport of nutrient solution needed by the plant, making it a viable option for production, even in adverse conditions. The availability of these nutrients in large quantities, in the form of organic fertilization (cattle manure), favored the plants of treatment T5 to obtain the best yield. Table 5 shows that the treatments T2, T3 and T4, to which wastewater was applied, at different depths and application forms, showed satisfactory results, since the productivity was higher than in non-irrigated treatments (T1 and T6), with or without fertilization. The yield in treatments receiving wastewater (T2, T3 and T4) was lower than that in treatment T5, which received the same irrigation depth with common water as T2, T3 and T4 but received organic fertilization (60 Mg ha^{-1}). The dry matter content was higher in the non-irrigated treatments than in the irrigated treatments, possibly due to the intense water deficit naturally imposed on the plants of these treatments. Observing the CAI data (Figure 6) together with the yield data (Table 5), it can be seen that the higher CAI of the T6 treatment in relation to the wastewater treatments (T2, T3 and T4) did not translate to higher productivity due to the high plant mortality in the T6 treatment, which did not occur in the treatments irrigated with wastewater. This confirms the importance of irrigation with wastewater, even with deficits, in ensuring productivity throughout the useful life of the crop.

CONCLUSION

The application of only 0.6 liters of wastewater per linear meter of cultivation once a week is sufficient to increase the survival rate of ‘Gigante’ cactus pear (*Opuntia ficus indica*) under prolonged drought conditions. Wastewater application provides higher productivity in ‘Gigante’ cactus pear (*Opuntia ficus indica*) than rainfed cultivation.

ACKNOWLEDGEMENT

The authors thank the National Council for Scientific and Technological Development (CNPq) for funding the research and granting scholarship.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

AUTHORS’ CONTRIBUTIONS

This work was carried out in collaboration with all the authors. JAAS designed the study, performed the statistical analysis, aided by DBT, wrote the protocol and wrote the first draft of the manuscript. DBS carried out analyses of the study, oversaw the conduction of the research and reviewed drafts of the manuscript. The authors TCC and GAR collected the data. The authors JAS and SLRD managed the literature searches and reviewed all drafts of the manuscript. All authors have read and approved the final manuscript.

REFERENCES

ASAE (American Society of Agricultural Engineers). Standard engineering practices data: EP458. Field evaluation of microirrigation systems. St. Joseph: ASAE 1996, p. 972-797.

BRASIL. Resolution CONAMA 357/2005. Conselho Nacional de Meio Ambiente. Avaliablein: <http://www2.mma.gov.br/port/conama/ legiabre.cfm?codlegi=459>. Accessed June 11, 2019.

CARVALHO, A. A. de; SILVA, T. G. F. da; SOUZA, L. S. B. de; MOURA, M. S. B. de; ARAUJO, G. G. L. de; TOLÊDO, M. P. S. Umidade do solo em lavouras de palma forrageira com práticas de melhoria da sua resiliência. Revista Brasileira Engenharia Agrícola Ambiental, vol.21, n.7, p. 481-487, 2017.

CAVALCANTE, L. A. D., SANTOS, G. R. A., SILVA, L. M., FAGUNDES, J. L., SILVA, M. A. Respostas de genótipos de palma forrageira a diferentes densidades de cultivo. Pesquisa Agropecuária Tropical, vol. 44, n. 4, p. 424 - 433, 2014.

CONSOLI, S., INGLESE, G., INGLESE, P. Determination of evapotranspiration and annual biomass productivity of a cactus pear [*Opuntia ficus-indica* L. (Mill.)] orchard in a semiarid environment. Journal of Irrigation and Drainage Engineering, vol.139, p. 680-690, 2013.

CORDOVA-TORRES, A. V., COSTA, R. G., MEDEIROS, A. N. de; ARAÚJO FILHO, J. T., RAMOS, A. O., ALVES, N. de L. Performance of sheep fed forage cactus with total water restriction. Revista Brasileira de Saúde e Produção Animal, v.18, n.2, p.369-377, 2017.

CORREIA, R. C., KILL, L., MOURA, M., CUNHA, T. F., JESUS, A., ARAÚJO, J. L.. A região Semiárida brasileira. In: VOLTOLINI, T. V. Produção de Caprinos e Ovinos no Semiárido. Petrolina, PE, Brasil: Embrapa, 2010. p. 21-48.

CRIDDLE, W.D., DAVIS, S., PAIR, C.H., SHOCKLEY, D.G. Methods for Evaluating Irrigation Systems. Washington DC: Soil Conservation Service - USDA, 1956. 24p. Agricultural Handbook, 82.

CUNHA, F. N., SILVA, N. M., TEIXEIRA, M. B., CARVALHO, J. J., MOURA, L. M. F., SANTOS, C. C. . Coeficientes de uniformidade em sistema de irrigação por gotejamento. Revista Brasileira de Agricultura Irrigada, vol.8,nº.6, p.444 - 454, 2014.

DONATO, P. E. R., PIRES, A. J. V., DONATO, S. L. R., BONOMO, P., SILVA, J. A., AQUINO, A. A. Morfometria e rendimento da palma forrageira "Gigante" sob diferentes espaçamentos e doses de adubação orgânica. Revista Brasileira de Ciências Agrárias, vol.9, n.1, p. 151-158, 2014.

DUARTE, J. G. P., FARIAS, A. A. de; SOUSA, F. de A. S. de; SOUZA, J. T. A., RAMOS, M. M. Q. Secas e Impactos na Agropecuária no Município de Campina Grande - PB. Revista Brasileira de Meteorologia, v.33, n.2, p.289-297, 2018.

EMBRAPA. Centro Nacional de Pesquisa de Solos. Sistema brasileiro de classificação de solos. Rio de Janeiro: Embrapa Solos. 1999. 412 p.

FERREIRA, D. F. Sisvar: a computer statistical analysis system. Ciência e Agrotecnologia, v. 35, n. 6, p. 1039–1042, 2011.

FERREIRA, D. F. Sisvar: a Guide for its Bootstrap procedures in multiple comparisons.Ciência e Agrotecnologia, vol. 38, n.2, p. 109 -112, 2014.

FONSECA, V. A. et al. Morpho-physiology, yield, and water-use efficiency of Opuntia ficus-indica irrigated with saline water. Acta Sci., Agron. [online]. 2019, vol. 41, e42631. Epub June 13, 2019. Doi.org/10.4025/actasciagron.v41i1.42631.

LEMOS, M. de; FERREIRA NETO, M., MEDEIROS, J. F. de; DIAS, N. da S., SILVA, Ê. F. de F. E., LIRA, R. B. de. Nutritional evaluation of forage cactus fertirigat with domestic sewage effluent. Revista Caatinga, v.31, n.2, p.476-486, 2018.

LIMA, G. F. C., REGO, M. M. T., AGUIAR, E. M., SILVA, J. G. M., DANTAS, F. D. G., GUEDES, F. L., LOBO, R. N. B. Effect of different cutting intensities on morphological characteristics and productivity of irrigated nopalea forage cactus. Acta Horticulturae, vol.1067, p.253-258, 2015. VIII International Congress on Cactus Pear and Cochineal.

MACAN, N. P. F., GOMES, T. M., ROSSI, F., TOMMASO, G.. Desempenho da irrigação por gotejamento com o uso de efluente de laticínio tratado por processo biológico. Irriga, vol. 22, n. 3, p. 575-590, 2017.

MANTOVANI, E. C. Avalia: Programa de avaliação da irrigação por aspersão e localizada. Viçosa, MG: UFV, 2001.

MEDEIROS, S. S., GHEYI, H. R., PEREZ-MARIN, A. M., SOARES, F. A. L., FERNANDES, D. Características químicas do solo sob algodoeiro em área que recebeu água residuária da suinocultura. Revista Brasileira de Ciência do Solo, Viçosa, vol. 35, p.1047 1055, 2011.

NASCIMENTO, V. F., FEITOSA, E. O., SOARES, J. I. Uniformidade de distribuição de um sistema de irrigação por aspersão via pivô central. Revista de Agricultura Neotropical, Cassilândia-MS, vol. 4, n. 4, p. 65-69, 2017.

PADILHA JUNIOR, M. C., DONATO, S. L. R., SILVA, J. A. DA; DONATO, P. E. R., SOUZA, E. S. Características morfométricas e rendimento da palma forrageira 'Gigante' sob diferentes adubações e configurações de plantio. Revista Verde de Agroecologia e Desenvolvimento Sustentável, vol.11, p. 67-72, 2016.

PEREIRA, P. de C., SILVA, T. G. F. da; ZOLNIER, S., MORAIS, J. E. F. de; SANTOS, D. C. 2015. dos. Morfogênese da palma forrageira irrigada por gotejamento. Revista Caatinga, Mossoró , v.28, n.3, p.184-195.

PINTO, M. S. C., MENEZES, R. S. C., SAMPAIO, E. V. S. B., ANDRADE, A. P., PIMIENTA FILHO, E. C., ANDRADE, M. V. M., FIGUEIREDO, M. V. et al. 2002. Estimativa do peso da palma forrageira (*Opuntia* ficus-*indica,* Mill.) a partir de medidas dos cladódios. In: Reunião Anual da Sociedade Brasileira de Zootecnia, 39. Recife - PE, 2002. Anais... Recife-PE: SBZ, vol.1. p. 54-64.

QUEIROZ, M. G., SILVA, T. G. F., ZOLNIER, S., SILVA, S. M. S., LIMA, L. R., ALVES, J. O. 2015. Características morfofisiológicas e produtividade da palma forrageira em diferentes lâminas de irrigação. Revista Brasileira de Engenharia Agrícola e Ambiental, Campina Grande, vol. 19, n.10, p. 931-938.

RAMOS, J. P. F., SANTOS, E. M., PINHO, R. M. A., BEZERRA, H. F. C., PEREIRA, G. A., BELTRÃO, G. R., OLIVEIRA, J. S. 2015. Crescimento da palma forrageira em função da adubação orgânica. Revista eletrônica de Veterinária. vol.16, n.12.

SILVA, D. J., QUEIROZ, A. C. 2009. Análise de alimentos: métodos químicos e biológicos.Viçosa, MG: UFV. 3ª edição, 4ª reimpressão. 235 p.

THORNTHWAITE, C.W., MATHER, J. R. 1955. The water balance. Publications in Climatology. New Jersey: Drexel Institute of Technology; 104p.

WILKINSON S., HARTUNG W. 2009. Food production: reducing water consumption manipulating long-distance chemical signalling in plants. J. Exp. Bot. 60, 1885–1891. DOI:10.1093/jxb/erp121

****