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Water footprint of ‘Gigante’ cactus pear with deficit irrigation using wastewater and blue water plus cattle manure

Pegada hídrica do cultivo de palma forrageira ‘Gigante’ com irrigação com déficit controlado usando águas residuárias

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ABSTRACT

This study aims to evaluate the water footprint of cactus pear cultivated under different irrigation strategies. Treatments were: no fertilization and no irrigation (T1); no fertilization and deficit irrigation (DI) with wastewater (0.6 L plant^{-1} week^{-1}) (T2); no fertilization and DI with wastewater (1.2 L plant^{-1} week^{-1}, once a week) (T3); no fertilization and DI with wastewater (1.2 L plant^{-1}week^{-1}, divided in two weekly applications) (T4); with organic fertilization (60 Mg ha^{-1} of bovine manure) and DI with blue water (1.2 L plant^{-1} week^{-1}) (T5); and with organic fertilization (60 Mg ha^{-1} of bovine manure) and no irrigation (T6). Treatments were arranged in a completely randomized blocks design, with five replicates. Productivity, nutrients applied and consumption of green and blue water were evaluated. The water footprint was lower in treatments irrigated with wastewater than in the other treatments. The DI, using blue water, makes it possible to increase crop productivity without increasing water footprint; in the absence of irrigation, organic fertilization does not reduce the water footprint; the DI, using wastewater, makes it possible to increase crop productivity while decreasing water footprint.

Keywords: Fertigation; domestic sewage; *Opuntia fícus-indica*; water use efficiency.

RESUMO

Este estudo objetivou avaliar a pegada hídrica da palma forrageira 'Gigante' com irrigação com déficit controlado (RDI) utilizando águas residuárias. Os tratamentos foram: sem adubação e sem irrigação (T1); sem adubação e RDI com efluentes (0,6 L planta^{-1} semana^{-1}) (T2); sem adubação e RDI com efluentes (1,2 L planta^{-1} semana^{-1}, uma vez por semana) (T3); sem adubação e RDI com efluentes (1,2 L planta^{-1} semana^{-1}, dividida em duas aplicações semanais) (T4); com adubação orgânica (60 Mg ha^{-1} de esterco bovino) e RDI com água comum (1,2 L planta^{-1} semana^{-1}) (T5); e com adubação orgânica (60 Mg ha^{-1} de esterco bovino) e sem irrigação (T6). O delineamento foi em blocos casualizados, com cinco repetições. Foram avaliados: produtividade; nutrientes aplicados; e consumo de água verde e azul. A pegada hídrica foi menor nos tratamentos irrigados com águas residuárias do que nos demais; o RDI, com água comum, permite aumentar a produtividade sem aumentar a pegada hídrica; na ausência de irrigação, a fertilização orgânica não reduz a pegada hídrica; o RDI, com águas residuárias, permite aumentar a produtividade enquanto diminui a pegada hídrica; e o uso de águas residuárias para irrigação diminui a pegada hídrica.

Palavras-chave:fertirrigação; *Opuntia fícus-indica*; eficiência de uso de água.

INTRODUCTION

In Brazil, the semi-arid region covers 60% of the Northeast region. The climate is characterized by low and irregular precipitations and high evapotranspiration. These characteristics constitute stress factors, both for livestock and agriculture, making forage production scarce during prolonged periods of drought, which may last up to nine months.

An alternative agricultural product for this region is the ‘Gigante’ cactus pear (*Opuntia fícus-indica* Mill). This crop has high water use efficiency, high productivity, high digestibility, and is capable of storing large amounts of water in its tissues, which is a strategic water reserve for the herds.

This crop has the characteristic of closing the stomata during the day and opening them at night for CO_2 fixation, resulting in water saving. However, despite this crop being adapted to adverse conditions, such as high evapotranspiration rate and water deficit, plants lose vigor and may die over the dry season due to excessive water loss, requiring water supplementation during this period to maintain productivity.

Management strategies, such as combination of spacings and fertilization, in cactus pear production tend to increase productivity (Silva et al., 2012). Coupled with these strategies, one alternative to ensure this productivity throughout the year is to use irrigation to supply, in whole or in part, the crop water demand (Souza et al., 2019). However, since water resources in this region are limited, alternatives for using this resource more efficiently are necessary.

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 the 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.

The use of domestic sewage to irrigate crops is an option when conventional water resources are scarce or nonexistent. It is an increasingly practice in agriculture as it has several advantages such as availability throughout the year and nutrient supply for crops. When drip irrigation is used, the contamination of soil surface by fecal coliforms was minimum and without any risk to human health (Souza et al., 2011).

Souza et al. (2011), studying drip irrigation in coffee with wastewater, declare that there is virtually no contamination by these microorganisms one day after irrigation, which is mainly due to ultraviolet radiation, which is very effective in eliminating these microorganisms; and due to the ability of soil to inactivate these organisms, either by predation by other organisms, competition for food or, mainly, by decreasing soil moisture.

Agriculture is the sector of the economy that most consumes freshwater. Even rain-fed agriculture consumes a lot of water, the so-called green water (Hoekstra et al. 2011). In volume, irrigated agriculture consumes more water than rain-fed agriculture, but in terms of water use efficiency, i.e., the amount of water consumed per kilogram of commercial product, usually irrigated agriculture is more efficient than rain-fed agriculture (Oweis et al., 2000).

According to Hoekstra et al. (2011), the water footprint (WF) of a product is the volume of freshwater used to produce the product over the full supply chain. It shows, specified in space and time, water consumption volumes by source (green and blue WFs) and polluted volumes (grey WF) by type of pollution.

Through the water footprint it is possible to monitor the human impact on the environment. Thus, it acts as an indicator of sustainability, aiming to evaluate the environmental impacts of production and consumption (Silva et al. 2013). Therefore, the concept of water footprint, spread by the scientific community, has the purpose of demonstrating the importance of water management for the environment.

This work aims to evaluate the water footprint in the ‘Gigante’ cactus pear with deficit irrigation (DI) using wastewater, without other fertilization than that provided by wastewater, compared to DI using blue water plus organic fertilization and to non-irrigated treatments, with and without fertilizers.

MATERIAL AND METHODS

The experiment was installed at the Federal Institute of Education, Science and Technology Baiano, Campus Guanambi, Guanambi, Bahia, Brazil, Latitude 14º 13' 30"S and Longitude 42º 46' 53" W. Semi-arid is the predominate climate, with mean annual rainfall of 663.69 mm, annual average evapotranspiration rate of 1961.6 mm and a mean temperature of 26 °C. The soil was classified as a medium-textured typical dystrophic yellow-red Latosol with a weak A horizon.

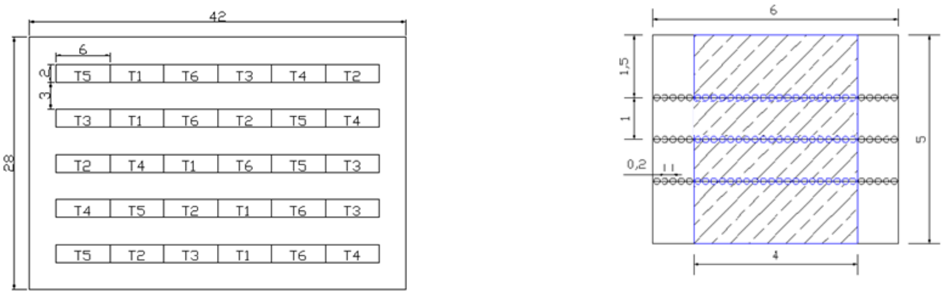
To estimate the water footprint, both the productivity and crop water balance of ‘Gigante’ cactus pear (*Opuntia fícus-indica* Mill) were evaluated. The experiment was designed in randomized blocks with six treatments and five replicates. The treatments were:

•T1: no fertilization and no irrigation;

- •T2: no fertilization and DI with wastewater (0.6 L plant^{-1}week^{-1});
- •T3: no fertilization and DI with wastewater (1.2 L plant^{-1}week^{-1}, applied once a week);
- •T4: no fertilization and DI with wastewater (1.2 L plant^{-1}week^{-1}, divided in two applications of 0.6 L plant^{-1});
- •T5: with organic fertilization (60 Mg ha^{-1} of bovine manure, applied before planting) and DI with blue 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 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. Figure 1 illustrates the randomized block design used (a) and details of the experimental plot, with the evaluation plot hatched in blue (b).

Figure 1 – Scheme of the experimental design in randomized blocks (a) and detail of the experimental plot, with the useful area hatched in blue (b)



(a)

(b)

The area was subsoiled, plowed, harrowed and then furrowed with a distance of 1 m between furrows. Bovine manure was applied only in the planting furrow of the plots of the treatments T5 and T6 (60 Mg ha^{-1}). Mature cladodes with good accumulation of reserves were selected on another cactus pear plantation of the campus. After harvesting, they remained shaded for 15 days to cure, and then, they were planted. The cladodes were planted with the widest portion buried about 50% in the soil for better fixation at a distance of 1 m between the planting rows on which the cladodes were 20 cm apart. Weeds were mechanically controlled during the experiment. Planting was completed at the end of October 2015.

The wastewater used in the experiment was collected in the stabilization pond of the campus, which receives domestic sewage collected from campus buildings, and was stored for 24 hours in a water tank (5,000 L) before using it for irrigation, so that the larger particles could settle on the bottom of the tank, thereby reducing clogging problems.

The blue water was collected in a tubular well installed on the campus and stored in a water tank (500 L). Both irrigations, with blue and wastewater, were performed by a drip irrigation system consisting of submersible pump, disk filter and emitters with nominal flow equal to 1.5 L h^{-1}, at a pressure of 150 kPa, spaced apart on the lateral line by 0.5 m. This spacing allowed forming a 0.5-m-wide wet band along the planting line. This wet band represented 30% of wet area.

Irrigation began in 18 April 2016, after the end of the rainy season, and lasted until 21 August 2017. In the treatment T2, the irrigation time was equal to 1.0 h, once a week; in treatments T3 and T5, it was equal to 2.0 h, once a week; in the treatment T4, it was equal to 1.0 h, twice a week. These times, combined with the flow of the emitters and the planting stand, 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.

Five evaluations were performed to determine the amount of nutrients present in the wastewater. Evaluations were made every four months, from April 2016 to August 2017. The average macro- and micronutrient contents present in wastewater and bovine manure are shown in Table 1. Based on the manure characteristics, it was calculated how much it contributed in terms of nutrients to treatments T5 and T6.

Table 1 – Macro- and micronutrients levels present in wastewater (WW) and bovine manure (BM)

Macronutrients	WW	BM	Micronutrients	WW	BM
	mg L^{-1}	mg kg^{-1}		mg L^{-1}	mg kg^{-1}
N	7.98	5200	Cu	0.006	45.2
P	4.7	4700	Fe	4.6	1932.4
K	65.6	2500	Mn	0.002	391.8
S	-	2300	Zn	0.002	200.5
Ca	200	1700			
Mg	30	200			

At each evaluation of the wastewater, the irrigation system was also evaluated, analyzing the mean weekly water depth (Dm) and the distribution uniformity (DU), at each irrigated treatments. The calculation of Dm took into account the mean flow rates (Fm) multiplied by the irrigation time of each treatment and divided by the wet area of the emitter.

The total volume of blue water and wastewater applied to each treatment (L ha^{-1}) was obtained by multiplying Fm by the number of emitters per hectare, weekly irrigation time and the number of weeks on which irrigation was performed. The wastewater volume multiplied by the wastewater nutrient contents results in the contribution of nutrients ($L_{nutrient}$) to plants in treatments T2, T3 and T4.

Table 2 shows the values of the contributions of macro- and micronutrients to the soil in treatments that received irrigation with wastewater (T2, T3 and T4) and in treatments that received organic fertilization with 60 Mg ha^{-1} of bovine manure (T5 and T6). In the treatments with wastewater, the total volume of water applied per area (L ha^{-1}) during the experiment was multiplied by the mean contents (mg L^{-1}) of each nutrient in the wastewater, shown in Table 1, and the results were converted into kg ha^{-1}.

Table 2 – Amount of macro and micronutrients applied to the soil via wastewater (T2, T3 and T4) and via fertilization with bovine manure with 60 Mg ha^{-1} (T5 and T6)

Treatment	K	Ca	P	Mg	Fe	Cu	Zn	Mn	N
					(kg ha^{-1})				
T2	100.2	234.0	5.5	35.1	5.4	0.007	0.002	0.002	9.3
T3	189.6	443.0	10.4	66.4	10.2	0.013	0.004	0.004	17.7
T4	189.6	443.0	10.4	66.4	10.2	0.013	0.004	0.004	17.7
T5	150.0	102.0	282.0	12.0	115.9	2.712	12.030	23.508	312.0
T6	150.0	102.0	282.0	12.0	115.9	2.712	12.030	23.508	312.0

T2: no fertilization and DI with wastewater (0.6 L plant^{-1} week^{-1}); T3: no fertilization and DI with wastewater (1.2 L plant^{-1} week^{-1}); T4: no fertilization and DI with wastewater (0.6 L plant^{-1}, two applications per week); T5: with organic fertilization (60 Mg ha^{-1}) and DI with blue water (1.2 L plant^{-1} week^{-1}); T6: no irrigation and with organic fertilization (60 Mg ha^{-1}).

Precipitation and reference evapotranspiration (ETo) data, obtained from an automatic weather station installed at the campus, and Dm were used to compute the crop water balance (CWB), according to the method proposed by Thornthwaite and Mather (1955), for the whole experimental period (670 days), to determine the water deficit of the crop in all treatments.

For determination of crop yield, all 60 plants of the evaluation unit of each plot were harvested and weighed. The crop yield (Y, kg ha^{-1}) was determined by multiplying the total mass of each evaluation unit (kg evaluation unit^{-1}) by 10,000 m^{2} ha^{-1}and dividing by 20 m^{2} evaluation unit^{-1}, simply put, multiplying the total mass of each plot by 500. Samples of six plants were collected randomly from each evaluation unit to determine the dry matter contents.

The green water footprint is the volume of rainwater consumed during the production process. It refers to the total rainwater evapotranspiration (from fields and plantations) plus the water incorporated in the harvested crop (Hoekstra et al. 2011). In this study, we considered the crop actual evapotranspiration (ETa) occurred during the whole cycle (670 days), obtained from the CWB.

The total water footprint (WF) of the process of growing crops is the sum of the green, blue and grey components (Equation 1) (Hoekstra et al. 2011):

$$WF = WF_{green} + WF_{blue} + WF_{grey} \tag{1}$$

Where:

WF_{green}, WF_{blue} and WF_{grey} are the green, blue and grey components of the WF, in L kg^{-1}, respectively.

The green component in the process water footprint of growing a crop (WF_{green}, L kg^{-1}) was calculated by the Equation 2. The blue component (WF_{blue}, L kg^{-1}) was calculated by the equation 3) (Hoekstra et al., 2011):

$$WF_{green} = \frac{CWU_{green}}{Y} \tag{2}$$

$$WF_{blue} = \frac{CWU_{blue}}{Y} \tag{3}$$

Where:

CWU_{green} and CWU_{blue} are the green and blue components in crop water use, in L ha^{-1}, respectively, and Y is the crop yield, in kg ha^{-1}.

The green and blue components in crop water use (CWU, L ha^{-1}) were obtained directly from the CWB. In the treatment irrigated with blue water (T5), the blue component was obtained by multiplying the irrigation depth (I, L m^{-2}) by the wet area (m^2 ha^{-1}). The green component was obtained by subtracting the irrigation depth from the ETa and multiplying the result by the wet area. In the remaining treatments, there was no blue component, and the green component was obtained by multiplying the ETa by the wet area.

There was no grey component in treatments T1, T5 and T6, since there was no application of chemical fertilization or chemical pest and disease control.

The grey water footprint of the wastewater is negative since it was used for irrigation a pollutant that would otherwise be released into a water body. Therefore, the use of wastewater for irrigation prevented this release, using the soil to inactivate pathogenic organisms. It was calculated by the Equation 4 (Hoekstra et al., 2011), using the phosphorus (P) load. P load was used for this calculation because this element was the most critical pollutant in the wastewater, considering the average contents in the wastewater and the maximum acceptable concentration of P in the receiving water body. Natural P concentration in the receiving water body (c_{nat}, in mass volume^{-1}) was not precisely known, but it was estimated to be low, and for simplicity was assumed $c_{nat} = 0$.

$$WF_{grey} = \frac{{}^{LP}/_{C_{max}}}{Y} \tag{4}$$

Where:

LP= P load, in kg;

c_{max}= maximum acceptable concentration of P in the receiving water body, kg L^{-1}; and

Y = crop yield, in kg ha^{-1}.

In order to calculate CWU_{grey}, the c_{max} for P was considered 0.05 mg L^{-1}, maximum acceptable concentration of P in the Class III receiving water body (BRASIL 2005), and the LP was calculated by multiplying the average P content in wastewater (Table 1) by the total volume of wastewater applied to treatments T2, T3 and T4.

The data were subjected to analysis of variance, adopting 5% as a critical level of significance. The averages were grouped by the Skott-Knott criterion, at 5% significance. Statistical analysis was performed using the statistical program "Sisvar" (FERREIRA 2014).

RESULTS

The average flow rates of the drippers, the distribution uniformity and the mean weekly water depth applied per irrigated treatment after five evaluations of the irrigation system are shown in Table 3.

Table 3 – Mean flow rates of the drippers (Fm), distribution uniformity (DU) and mean weekly water depth (Dm) applied per irrigated treatment

Treatment	Fm (L h^{-1})	DU (%)	Dm (mm)
T2	1.495	95	5.98
T3	1.441	94	11.53
T4	1.443	94	11.53
T5	1.470	93	11.76

T2: no fertilization and DI with wastewater (0.6 L $plant^{-1}$ $week^{-1}$); T3: no fertilization and DI with wastewater (1.2 L $plant^{-1}$ $week^{-1}$); T4: no fertilization and DI with wastewater (0.6 L $plant^{-1}$, two applications per week); T5: with organic fertilization (60 Mg ha^{-1}) and DI with blue water (1.2 L $plant^{-1}$ $week^{-1}$).

Table 2 shows that the uniformity of water distribution (DU) ranged from 93 to 95%, which can be considered as excellent in all treatments, according to the evaluation criterion proposed by Mantovani (2001) (Excellent: DU>84%). The use of wastewater during the whole experiment did not negatively affect the DU and the average flow of the emitters, as the latter was close to the nominal flow reported by the manufacturer (1.5 L h^{-1}) in all treatments.

From Dm applied in all irrigated days, to obtain the total irrigation (I) in the irrigated treatments, the CWB was set up. For this: the ETo for the whole experimental period (670 days) was equal to 3,433.3 mm; the crop coefficient (Kc) was considered equal to 0.5 (Consoli, Inglese and Inglese 2013; Queiroz et al. 2016); and the Total Soil Water Storage Capacity (TWSC) was equal to 50.4 mm, calculated by the Equation 5 (Bernardo et al. 2006).

$$TWSC = \frac{(FC-PWP)\,Dg\,Z}{10} \qquad (5)$$

Where:

FC = Field Capacity (15%); PWP = Permanent Wilting Point (6%); Dg = soil global density (1.4), determined in the Soil Physics Laboratory of the institution; and Z = Depth of the Root System (40 cm).

Table 4 summarizes the CWBs in all treatments for the period from the last week of October 2015 to the fourth week of August 2017 (670 days), when the last irrigation in the crop was carried out, with the green, blue and grey components in crop water use (m^3 ha^{-1}).

Table 4 – Summary of the Crop Water Balance (CWB) in all treatments, from the last week of October 2015 to the fourth week of August 2017 (670 days)

Treatment	ETpc (mm)	P (mm)	I+P-ETc (mm)	ETa (mm)	CWU$_{green}$ (m^3 ha^{-1})	CWU$_{blue}$ (m^3 ha^{-1})	CWU$_{grey}$ (m^3 ha^{-1})	I (mm)	ETa/ ETc
T1	1716.65	923.52	-793.13	455.65	1,876.89			0.00	0.27
T2	1716.65	923.52	-923.52	769.80	2,819.35		-109,998.8	382.72	0.45
T3	1716.65	923.52	-55.00	1146.37	3,801.00		-208,201.7	738.13	0.67
T4	1716.65	923.52	-55.00	1146.37	3,800.00		-208,201.7	738.13	0.67
T5	1716.65	923.52	-40.49	1110.00	1,582.02	2,257.92		752.64	0.65
T6	1716.65	923.52	-793.13	455.65	1,876.89			0.00	0.27

T1: no fertilization and no irrigation;T2: no fertilization and DI with wastewater (0.6 L plant^{-1} week^{-1}); T3: no fertilization and DI with wastewater (1.2 L plant^{-1} week^{-1}); T4: no fertilization and DI with wastewater (0.6 L plant^{-1}, two applications per week); T5: with organic fertilization (60 Mg ha^{-1}) and DI with blue water (1.2 L plant^{-1} week^{-1}); T6: no irrigation and with organic fertilization (60 Mg ha^{-1}). ETc: potential crop evapotranspiration; P: rainfall; ETa: actual crop evapotranspiration; CWU$_{green}$: green component in crop water use; CWU$_{blue}$: blue component in crop water use; CWU$_{grey}$: grey component in crop water use; I: irrigation; ETa/ ETc: relative crop evapotranspiration

Table 5 shows that the WF was lower in treatments irrigated with wastewater than in the other treatments, as these did not differ from one another (P=.01). This was due to an increase in yield without using blue water for irrigation. The mean values of the green matter yield of cactus pear differed from each other (P=.05) as a function of irrigation and organic fertilization. In the non-irrigated treatments, the yields were lower than in the remaining treatments (P=0.05).

Table 5 – Average of water footprint (WF), in $m^3 Mg^{-1}$, yields of green matter (GM) and dry matter (DM), in kg ha^{-1}, and dry matter content (DM content), in %, of 'Gigante' cactus pear in each treatment.

Treatment	WF*** ($m^3 ton^{-1}$)	Yield (kg ha^{-1}) GM**	Yield (kg ha^{-1}) DM*	DM content** (%)
T1	63.55 B	91,350 A	11,049 A	11.98 B
T2	32.54 A	179,000 B	13,818 A	7.77 A
T3	29.29 A	186,550 B	13,173 A	6.98 A
T4	31.40 A	171,450 B	12,238 A	7.13 A
T5	55.86 B	258,700 C	16,821 B	6.75 A
T6	62.14 B	104,850 A	11,378 A	10.92 B

Means followed by the same letter do not differ significantly from each other (*P=.1, **P=.05, ***P=.01), by the Scott-Knott test.T1: no fertilization and no irrigation; T2: no fertilization and DI with wastewater (0.6 L $plant^{-1}$ $week^{-1}$); T3: no fertilization and DI with wastewater (1.2 L $plant^{-1}$ $week^{-1}$); T4: no fertilization and DI with wastewater (0.6 L $plant^{-1}$, two applications per week); T5: with organic fertilization (60 Mg ha^{-1}) and DI with blue water (1.2 L $plant^{-1}$ $week^{-1}$); T6: no irrigation and with organic fertilization (60 Mg ha^{-1}).

In Table 5, regarding fresh matter yield, there was no difference between treatments with irrigation using wastewater (T2, T3 and T4). These treatments had a higher mean than the mean of non-irrigated treatments, either with or without organic fertilization, namely T6 and T1, respectively, and these two treatments were equal.

Considering the load of pollutants (L) to calculate CWU_{grey} in treatments that received irrigation with wastewater (T2, T3 and T4), the highest values are for Ca, K and Mg, respectively. However, there is no maximum acceptable concentration of these ions in the receiving water body established by the legislation (BRASIL, 2005). The fourth highest L is N, but the c_{max} of N is 11 mg L^{-1} (BRASIL 2005); therefore, the most critical pollutant was P (c_{max}= 0.05 mg L^{-1}).

Table 6 shows the average of green, blue and grey water footprint (WF_{green}, WF_{blue} and WF_{grey}, respectively) and net water footprint (WF_{net}), in L kg^{-1}, in the treatments T2, T3 and T4, when the negative WF_{grey} was used to calculate WF. By dividing WF_{grey} by WF_{green} of the treatment T4, it can be seen that the water saved in the river basin, which would be used to neutralize the P load, was 38.67 times greater than the crop water consumption.

Table 6 – Average of green, blue and grey water footprint (WF_{green}, WF_{blue} and WF_{grey}, respectively) and net water footprint (WF_{net}), in m^3ton^{-1}, in the treatments T2, T3 and T4, when the negative WF_{grey} was used to calculate the water footprint.

Treatment	WF_{green}	WF_{blue}	WF_{grey}	WF_{net}
			(m^3ton^{-1})	
T2	32.54	0	-614.52	-581.98
T3	29.29	0	-1116.06	-1086.78
T4	31.40	0	-1214.36	-1182.96

T2: no fertilization and DI with wastewater (0.6 L $plant^{-1}$ $week^{-1}$); T3: no fertilization and DI with wastewater (1.2 L $plant^{-1}$ $week^{-1}$); T4: no fertilization and DI with wastewater (0.6 L $plant^{-1}$, two applications per week).

DISCUSSION

Table 4 shows that even in a 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-ETa/ETc)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. Considering that the yield response to ET is expressed as [(1-Ya/Yp)=Ky(1-ETa/ETc)], where Yp and Ya are the potential and actual yields and Ky is a yield response factor representing the effect of a reduction in evapotranspiration on yield losses (Smith & Steduto, 2012), the crop may have lost approximately three-quarters of its productive potential.

On the other hand, the treatment with organic fertilization and water supplementation with blue water (1.2 L $week^{-1}$ $plant^{-1}$) (T5) had the highest productivity (Table 4). Looking again at Table 3, it can be seen that the water deficit in this treatment (T5) was equal to 35%, that is, the crop had not transpired just over a third of its potential evapotranspiration.

This higher evapotranspiration in the treatment T5, associated with organic fertilization, allowed plants of this treatment to reach higher productivity than plants of other treatments. Thus, despite using blue water for supplemental irrigation, the water footprint of the treatment T5 did not differ from non-irrigated treatments (T1 and T6). This means that deficit irrigation made it possible to increase productivity without increasing the water footprint.

By comparing T5 with T6, both had the same fertilization, the ETa of T5 was 2.44 times higher than T6 and the green matter yield was 2.47 times greater. A near linear relationship between relative ETa and relative productivity demonstrates the beneficial effect of irrigation on productivity, even with only 1.2 L $week^{-1}$ $plant^{-1}$. In other words, the deficit irrigation (deficit equal to 35%), using blue water (T5), provided a green matter yield 2.47 times higher than in non-irrigated treatment (T6 - water deficit equal to 73%), with the same fertilization, without increasing the water footprint.

Even without organic fertilization, DI with wastewater was fundamental for increasing crop productivity, and consequently, the water footprint was smaller than non-irrigated treatments.

In the absence of irrigation, fertilization with 60 Mg ha^{-1}, performed in T6, did not contribute to increasing productivity compared to T1, probably due to the intense water deficit of the crop (73%) in both treatments, which impaired the mineralization of organic matter in T6, affecting nutrient uptake by plants. Consequently, in the absence of irrigation, fertilization with 60 Mg ha^{-1} did not contribute to reduce the water footprint.

Even in the treatment T2, to which only 0.6 L week^{-1} plant^{-1} was applied, reducing the water deficit to 55%, the application of wastewater was fundamental to increasing the productivity of fresh matter, even without organic fertilization. Comparing only T2 with T1, the ETa of the former was 1.69 times higher than the latter and the productivity was 1.96 times higher. This relationship is even better than the linear relationship that occurred when comparing T5 with T6. Simply put, the DI (deficit equal to 55%), using wastewater (T2), provided a yield of fresh matter 1.96 times higher than in the non-irrigated treatment T1 (water deficit equal to 73%). This indicates that the water footprint in the treatment T1 was also 1.96 times higher than in the treatment T2. That is, the use of wastewater for irrigation increases crop productivity, while reducing the water footprint in the same proportion, since it does not use blue water to irrigate.

Considering that, in both treatments there was no organic fertilization, here is the beneficial effect on productivity, and consequently on the water footprint, not only from irrigation but also from the nutrients contained in the wastewater, even with only 0.6 L week^{-1} plant^{-1}. This amount of water reduced the deficit from 73% to 55%, which is still considered high for most crops. This also demonstrates high water use efficiency in ‘Gigante’ cactus pear plants.

In order to calculate WF for the treatments T2, T3 and T4, we did not consider the grey component (Table 4) because this WF_{grey} occurred in another process (education). It is the WF_{grey} that would occur if the wastewater generated by the educational institution had been dumped into the receiving water body instead of being used for irrigation. Therefore, the use of wastewater for irrigation prevented this release. If this wastewater had been dumped into the receiving water body, 94 L of clean water would be consumed to neutralize every liter of wastewater.

In the crop production process, the WF_{grey} is negative and much higher than the green component (Table 6) for treatments T2, T3 and T4. So, if WF_{grey} had been considered, the net WF in treatments T2, T3 and T4 would have been negative and of great magnitude.

According to Hoekstra et al. (2011), calculated negative grey water footprints have to be ignored from the accounts, in order to separate the discussion on one's actual positive water footprint from the discussion on one's possible role in terms of compensation. However, the use of wastewater for irrigation reduced the river basin water footprint, while still increasing crop yield with reduction of the crop production water footprint.

The reduction of the river basin water footprint was about 38 times greater than the crop production water footprint, in the treatments T3 and T4, to which 1.2 L of wastewater plant^{-1} week^{-1} was applied. This makes the irrigation with wastewater a highly sustainable method.

Treatment T5 had the highest productivity, even though the same amount of water was applied to treatments T3 and T4. This is possibly explained by the greater amount of nutrients applied through fertilization with manure (60 Mg ha^{-1}) than with wastewater. As can be seen in Table 5, only in relation to K, Ca and Mg, the contributions were higher in the treatments with wastewater than with manure, but in the same order of magnitude. As for all other nutrients, fertilizer intake with manure was much higher than with wastewater for P, N and all micronutrients. Although the yield for the treatment T5 was higher than for treatments T3 and T4, the water footprint for T5 was also higher than for treatments T3 and T4, due to the use of blue water in T5.

Considering all treatments, the water footprint of the cactus pear ranged from 29.29 to 63.55 m³ Mg^{-1}. These values are much lower than those reported in the literature for the most diverse crops, including cactus pear: Carvalho & Menezes (2014) found water footprints much greater in sorghum (1,561 m³ Mg^{-1}), buffel grass (1,527 m³ Mg^{-1}), maize (955 m³ Mg^{-1}) and cactus pear (296 m³ Mg^{-1}). The authors calculated water footprint by dividing total precipitation occurred during the period of plant growth (not ETa) for each final crop yield. Costa et al. (2018), working with different soybean cultivars, found water footprint equal to 991 m³ Mg^{-1} for the best cultivar, lower than the global mean values for soybean (2,144 m³ Mg^{-1}) reported by Mekonnen and Hoekstra (2010). Silva et al. (2015), working with different irrigation depths in sugar cane (from 0% to 100% of ETo), found the lower water footprint equal to 103.52 m³ Mg^{-1}in the rain-fed crop.

The results obtained in this research confirm the high water use efficiency of the cactus pear cultivated in the semi-arid region, mainly when it is used the deficit irrigation (DI) strategy.

CONCLUSIONS

The deficit irrigation, using blue water, makes it possible to increase the productivity of the cactus pear without increasing the water footprint.

In the absence of irrigation, organic fertilization does not reduce the water footprint.

The deficit irrigation, using wastewater, makes it possible to increase the productivity of the cactus pear while decreasing the water footprint.

The use of wastewater for irrigation contributes to decrease the water footprint.

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