Revista Ceres
ISSN: 0034-737X
ISSN: 2177-3491
Universidade Federal de Viçosa

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Revista Ceres, vol. 66, no. 1, January-February, 2019, pp. 34-40
Universidade Federal de Viçosa

DOI: 10.1590/0034-737X201966010005

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Production components of sunflower plants irrigated with treated domestic wastewater and drinking water in semiarid region[1]

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10.1590/0034-737X201966010005

ABSTRACT

This study aimed to evaluate production components of sunflower (*Helianthus annuus* L.) plants irrigated with domestic wastewaters treated by different processes, with two irrigation depths. The experiment was carried out in Ibimirim, state of Pernambuco, Brazil, using a randomized block design in a 4×2 factorial arrangement, with four replications. The treatments consisted of four irrigation water types (domestic wastewater treated by UASB reactor - DW_1; domestic wastewater treated by digestion decanter and anaerobic filtration - DW_2; domestic wastewater treated by anaerobic filtration - DW_3; and public water - PW_4) and two irrigation depths (equal to the crop evapotranspiration - ID_1; and 20% higher than the crop evapotranspiration - ID_2). The production components—plant fresh and dry weights, 1000-achene weight, capitulum internal diameter, achene yield, oil content, and oil yield—were evaluated at the end of the crop cycle. The irrigation with treated domestic wastewater improved all variables analyzed when compared to the drinking water, especially when using DW_2 and DW_3 with ID_1.

Keywords: water reuse; household effluents; sewage treatment; *Helianthus annuus* L.

RESUMO

Componentes de produção do girassol irrigado com esgotos domésticos tratados e água de abastecimento em região semiárida

Objetivou-se avaliar os componentes de produção do girassol (*Helianthus annuus* L.) irrigado com esgotos domésticos tratados por diferentes processos e duas lâminas de irrigação. O experimento foi realizado em Ibimirim-PE, Brasil. Utilizou-se o delineamento em blocos ao acaso, em esquema fatorial 4 x 2, com quatro repetições. Os tratamentos consistiram da utilização de dois fatores: tipos de águas de irrigação (ED_1 - esgoto tratado por reator UASB, ED_2 - esgoto tratado por decanto digestor e filtragem anaeróbia, ED_3 - esgoto tratado por filtragem anaeróbia e AB_4 - água de abastecimento) e lâminas de irrigação (L_1 - igual à evapotranspiração da cultura e L_2 - 20% superior à evapotranspiração da cultura). Ao final do ciclo da cultura, mensurou-se as variáveis relacionadas à produção: biomassa fresca e seca por planta, massa de mil aquênios, diâmetro interno do capítulo, produtividade de aquênios, teor e produtividade de óleo. Verificou-se que a irrigação com esgotos domésticos tratados proporcionou aumentos em todas as variáveis analisadas em relação à água de abastecimento, principalmente quando se fez uso das águas ED_2 e ED_3 com a lâmina L_1.

Palavras-chave: reúso de água; efluentes domésticos; tratamentos de esgoto; *Helianthus annuus* L.

Subjected on March 09th, 2018 and accepted on January 19th, 2019

[1] This work is part of the first author's doctoral thesis.

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INTRODUCTION

Water scarcity and quality have become a worldwide concern. The increase in the world population requires to increase food production, which generates greater water demand for agricultural activities (Savvas *et al.*, 2007; Cunha *et al.*, 2011; Nikolaou *et al.*, 2017).

Large volumes of domestic wastewater (DW) are released into the environment without adequate treatment causing damage to ecosystems (Bezerra & Fideles Filho, 2009). In Brazil, more than 90% of the domestic wastewater and approximately 70% of industrial effluents are released directly into water bodies without any treatment (Brasil, 2015).

Water reuse is not a new concept, but the increasing demand for water has turn planned water reuse into an important issue. Treated wastewater is important for the sustainable management of water resources for agriculture; it increases the water volume available and contribute to plant nutrition (Cunha *et al.*, 2011; Santos Júnior *et al.*, 2015).

The use of domestic wastewater in agriculture reduces pollution of water courses, saves good quality water, and lowers mineral fertilization costs (Deon *et al.*, 2010; Barbosa *et al.*, 2017; Gonçalves *et al.*, 2017).

DW should be treated to the secondary level for agricultural production purposes to reduce organic matter content and maintain essential nutrients to crops (Silva *et al.*, 2012). Anaerobic processes are widely used because they are efficient, fast, and low-cost methods (Singh & Prerna, 2009). Several types of anaerobic reactors can be used for wastewater treatment, such as the upflow anaerobic sludge blanket (UASB), digestion decanters, anaerobic filters, and combined processes.

Evaluations of the performance of crops irrigated with treated domestic wastewater have been carried out in Brazil (Nobre *et al.*, 2010; Freitas *et al.*, 2012; Orrico Junior *et al.*, 2013; Bezerra *et al.*, 2014; Santos Junior *et al.*, 2011; Santos Junior *et al.*, 2015; Barbosa *et al.*, 2017; Gonçalves *et al.*, 2017), with most of them finding improvements when comparing to irrigations with public water. In this context, the objective of this work was to evaluate production components of sunflower (*Helianthus annus* L.) plants grown in the Semiarid region of Brazil, irrigated with domestic wastewater treated by different processes, with two irrigation depths.

MATERIAL AND METHODS

The experiment was carried out in Ibimirim, state of Pernambuco, Brazil, at the Pilot Unit of Water Reuse in Agriculture (8º32’05"S, 37º41’58"W, and altitude of 408 m).

The region has a BSw’h’, very hot and dry climate, with a rainy season in the summer that can last until early fall, according to the Köppen classification, with average annual rainfall of 454 mm and average annual air temperature of 24.7 °C (Alvares *et al.* 2014; Instituto Nacional de Meteorologia - INMET, 2018). During the experiment, the average air temperature was 26.9 ºC and the accumulated rainfall depth was 175.2 mm (Figure 1).

The soil of the experimental area was classified as Entisol, with a moderate A horizon, and flat relief (Empresa Brasileira de Pesquisa Agropecuária - Embrapa, 2013). A chemical analysis of the 0-0.40 m soil layer was performed according to the methodology of Embrapa (2011) before the application of the DW. The soil presented pH (H_2O) of 7.0; 2.2 g kg^{-1} of total organic carbon, 56.85 mg kg^{-1} of P (Mehlich 1), 0.25 cmol$_c$ dm^{-3} of K, 2.15 cmol$_c$ dm^{-3} of Ca, 2.2 cmol$_c$ dm^{-3} of Mg, 3.1 cmol$_c$ dm^{-3} of H+Al, sum of bases of 5 cmol$_c$ dm^{-3}, cation exchange capacity of 8.05 cmol$_c$ dm^{-3}, and base saturation of 63.1%. Therefore, the soil had good fertility, intermediate cation exchange capacity at pH 7.0, intermediate potential acidity, and good organic carbon content (Alvarez *et al.*, 1999).

The experiment was conducted using a randomized block experimental design in a 4×2 factorial arrangement, with four replications. The treatments consisted of four irrigation water types (domestic wastewater treated by UASB reactor - DW_1; domestic wastewater treated by digestion decanter and anaerobic filtration - DW_2; domestic wastewater treated by anaerobic filtration - DW_3; and public water - PW_4) and two irrigation depths (equal to the crop evapotranspiration - ID_1; and 20% higher than crop evapotranspiration - ID_2).

The experimental unit consisted of three 6-meter planting rows. The sunflower seeds were sown with spacing of 0.25 m between plants and 1.0 m between rows, using the Helio-250 cultivar. A drip irrigation system was used, consisted of a polyethylene tube of 16 mm diameter with emitters spaced 0.33 m apart, flow rate of 4.0 L h^{-1}, and average operating pressure of 103 kPa. The mean coefficient of distribution uniformity of the system was 89%.

The irrigation depths were defined according to the crop evapotranspiration (ETc), using the crop coefficient (Kc) and reference evapotranspiration (ETo), through the Penman-Monteith method, standardized by the United Nations for Food and Agriculture - FAO (Allen *et al.*, 1998). The mean Kc found were 0.35 for the crop initial stages of germination, emergence, and establishment (20 to 25 days), 0.75 for the vegetative stage (35 to 40 days), 1.15 for the flowering stage (40 to 50 days), 0.75 for the grain filling stage (25 to 30 days), and 0.4 for the physiological maturation stage (Doorenbos & Kassam, 1979). The mean location coefficient was determined according to the methodology of Albuquerque *et al.* (2011).

Irrigation depths were altered according to the treatments at 27 day after sowing (DAS), with plants in ID_2 receiving 20% more water than those in ID_1, totaling 315.5 mm (ID_1) and 370.2 mm (ID_2) at the end of the cycle (Figure 1).

The physical-chemical (pH, electrical conductivity, chemical oxygen demand, and biochemical oxygen demand), chemical (N, P, K, Ca, Mg, Na, Cl, sodium adsorption ratio (SAR), SO_4^{-2}, $CaCO_3$), and physical (total suspended solids) parameters of the irrigation waters used were analyzed according to the Standard Methods for the Examination of Wastewater (APHA, 2012).

The plant fresh weight (PFW), plant dry weight (PDW), capitulum internal diameter (CID), 1000-achene weight (1000AW), achene production per plant (APP), achene yield (AY), oil content (AOC), and oil yield (AOY) were evaluated at 96 DAS. A grain moisture content of 11% was used to calculate 1000AW, APP, AY, AOC, and AOY. The Soxhlet extraction method was used to determine AOC (Bezerra Neto & Barreto, 2011).

The data were subjected to analysis of variance by the F test ($p<0.05$). The orthogonal contrasts 1 - $DW_1 \times DW_2$, 2 - $DW_1 \times DW_3$, 3 - $DW_1 \times PW_4$, 4 - $DW_2 \times DW_3$, 5 - $DW_2 \times (DW_1 + DW_3)$, 6 - $PW_4 \times (DW_1 + DW_2 + DW_3)$, and 7 - $ID_1 \times ID_2$ - were tested when the interaction between the factors was significant, using the SISVAR program (Ferreira, 2011).

RESULTS AND DISCUSSION

The average N, P, K, and Ca contents in the domestic wastewater used in the experiment were 88.5, 9.4, 46.5, and 136.6 mg L^{-1} respectively (Table 1). Considering the applied irrigation depth in ID_1 of 315.5 mm, the domestic wastewater contributed with 279.2, 29.8, 146.8, and 437.3 kg ha^{-1} of N, P, K, and Ca respectively, improving soil fertility, and discarding the need for commercial fertilizer applications. However, the domestic wastewater presented electrical conductivity of 2.0 dS m^{-1} and SAR of 1.82. According to Richards (1954), this type of water is classified as C3S1, present high risk of salinization, and can be used in soils with good drainage and with crops that present moderate tolerance to salinity. This denotes the need for studies of specific managements, such as the use of leaching fraction.

The use of domestic wastewater had significant effect on all variables evaluated, when compared to the public water (PW_4) (Table 2 - Contrast 6). Average increases of 333.6 g in PFW, 53.7 g in PDW, 3.23 cm in CID, and 18.1 g in 1000 AW were found, which increased AY to 1,614.4 kg ha^{-1} and AOY to 703 kg ha^{-1}.

The average PDW of plants irrigated with domestic wastewater (DW_1, DW_2, and DW_3) was 85.6 g, and 32 g with PW_4, denoting an average increment of 167% due to the use of wastewater. These results were higher than those found by Nobre *et al.* (2010) who found PDW of 10.9 to 41.5 g with increasing irrigation depths with domestic effluent, and organic fertilization, in a protected environment. An expressive increase in PDW of sunflower, which can be incorporated into the soil, or used for animal feed, can be obtained with the use of treated domestic wastewater in the irrigation water. According to Garcez *et al.* (2015), sunflower crop residues presents good degradability and can be included in diets of ruminants.

Plants irrigated with the domestic wastewater had higher 1000 AW, with no significant difference between them. The irrigation depths generated significant differences only when using DW_1, in which the use of ID_1 resulted in an 1000 AW of 27.7 g (46.2%) higher than ID_2 (Table 3). This effect was probably because of the precipitation of part of the calcium and phosphorus as calcium phosphate in the DW_1, which was higher when using the ID_2; whereas plants in PW_4 had lower 1000 AW due to nutrient deficit. The use of ID_2 increased the 1000 AW of plants treated with DW_2 (84.8 g) and DW_3 (75.3 g) in 35.02%, on average, when compared to those of plants treated with DW_1 and PW_4.

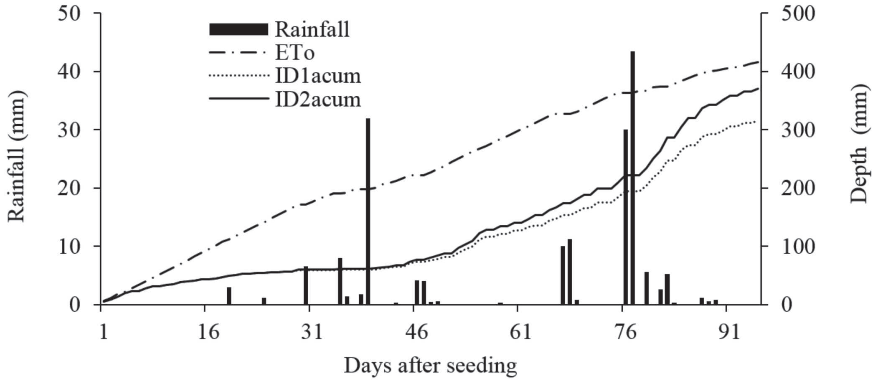

Figure 1: Rainfall depths, reference evapotranspiration, and accumulated irrigation depths during the experiment.

Table 1: Means values of phsical-chemical parameters (pH, EC, COD and BOD) and chemical (N, P, K, Ca, Mg, Na, Cl, RAS, SO_4^{-2}, $CaCO_3$) and phsical (SST) parameters of treated domestic sewage and water used for irrigation

Trat.	pH	EC	DQO	DBO	N	P	K	Ca	Mg	Na	Cl	RAS	SO_4^{2-}	$CaCO_3$	SST
		dS m^{-1}	mg L^{-1}									(mmol L^{-1})^{0,5}		mg L^{-1}	
ED_1	6,8	2,1	395,5	36,1	106,9	10,3	43,6	155,6	44,7	99,1	171,1	1,3	19,8	221,6	61,6
ED_2	6,8	1,9	384,6	47,3	74,3	8,7	42,4	109,5	62,9	116,6	159,0	1,5	89,6	196,2	44,3
ED_3	6,9	1,8	694,9	65,0	84,3	9,4	53,6	150,7	33,8	111,7	186,2	1,5	67,7	222,8	114,6
AB_4	6,5	0,2	10,8	0,9	-	0,3	13,3	32,1	20,6	22,5	38,3	0,5	5,2	81,3	22,4

Electrical conductivity (EC), chemical oxygen demand (COD), and biochemical oxygen demand (BOD), sodium adsorption ratio (SAR), total suspended solids (SST)

The 1000AW found were similar to those found by Aquino *et al.* (2013), who evaluated the same sunflower cultivar and found 1000AW of 86 g. In addition, Capone *et al.* (2011) and Pivetta *et al.* (2012) found 1000AW of 29.25 to 46.86 g in non-irrigated crops.

Plants irrigated with PW_4 had mean achene yield (AY) of 1,677.5 kg ha^{-1}, and those irrigated with treated DW had mean AY of 3,291.9 kg ha^{-1} (Table 2), representing an increase of 96.2%. These AY were higher than the national average in the 2016/17 harvest (1,419 kg ha^{-1}) (Companhia Nacional de Abastecimento - Conab, 2017) and higher than that found by Bezerra *et al.* (2014) (2,987.5 kg ha^{-1}), who evaluated the effect of irrigation with treated wastewater and nitrogen rates in sunflower crops in Aquiraz, CE, Brazil. However, the AY were lower than those found by Aquino *et al.* (2013) (3,950 kg ha^{-1}), who evaluated sunflower cultivars with mineral fertilization applied at planting (250 kg ha^{-1} of 8-28-16 N-P-K) and as top-dressing (80-0-60 kg ha^{-1} of N-P-K).

The higher AY of plants with the use of PW_4 when compared to the national yield can be due to the benefits of irrigation, through the maintenance of soil moisture and soil nutrient availability. The Helio-250 cultivar was evaluated in different sites in the Northeast region of Brazil, showing AY of 1,052 to 3,425 kg ha^{-1} (Empresa Brasileira de Pesquisa Agropecuária - Embrapa, 2010).

Increases in AY due to irrigation with domestic wastewater were found by Lobo & Grassi Filho (2007) and Nobre *et al.* (2010), who evaluated the efficiency of sewage sludge in supplying nitrogen, and water for sunflower crops.

DW_2, and DW_3 presented no significant differences ($p \geq 0.05$) in any variable analyzed (Table 2 - Contrast 4), denoting similarity between them. However, a significant effect ($p<0.05$) in AY was found between Contrasts 1 ($DW_1 \times DW_2$) and 2 ($DW_1 \times DW_3$) (Table 2), denoting higher AY with the use of DW_2 (3,644.4 kg ha^{-1}), and DW_3 (3,462.2 kg ha^{-1}) (Table 2). The use of DW_1 resulted in a lower AY than the use of DW_2, or DW_3 due to its lower sulfate concentration (SO_4^{-2}) (Table 1), making sulfur a limiting nutrient to the development of the crop, since this element is important to the synthesis of amino acids (Taiz *et al.*, 2017). Tiecher *et al.* (2012) found significant linear effect for the response of sunflower crops to sulfate fertilization, with increases in seed sulfur contents with increasing sulfate rates.

Achene oil content (AOC) had an average variation of 33% to 38.9% according to the irrigation water type. The analysis of the irrigation water types within each irrigation depth showed better results for the plots irrigated with domestic wastewater with ID_1 when compared to PW_4; and no significant difference ($p \geq 0.05$) was found for ID_2. The effect of the different irrigation depths in each type of water was significant only for PW_4, with a 25.2% increase in AOC when using ID_2 (Table 3). Thomaz *et al.* (2012) evaluated the effect of different sowing times on achenes production and oil content and found AOC ranging from 37 to 52%.

The achene oil yield (AOY) of the treatments DW_2 (1,415.5 kg ha^{-1}) and DW_3 (1,319.3 kg ha^{-1}) were significantly higher than those of the other treatments (p<0.05). The irrigation depths were also significant for AOY (Table 2); ID_1 resulted in an AOY of 16.53%. Gomes *et al.* (2012) found different results (linear effect), with increases in AOY of sunflower (Aragua 4 cultivar) with increasing irrigation depths.

The use of treated domestic wastewater significantly improved production variables in the region evaluated, where most plantations are carried out in rainfed systems, with no guarantee of harvest. Therefore, the use of treated domestic wastewater for irrigation is an alternative for this crop in regions with water scarcity.

Despite the benefits of using treated domestic wastewater, this technology requires adequate practices for treatment and disposal in the environment, since treated domestic wastewaters have considerable concentrations of dissolved ions such as sodium, boron, and chlorides, and contain diverse pathogenic organisms such as bacteria, viruses, protozoa, and helminths (Sousa *et al.*, 2003; Hespanhol, 2009). Therefore, an inadequate management of these wastewaters can harm the environment, human health, soil, aquifers, and irrigated crops (Duarte *et al.*, 2008). Moreover, this can cause soil salinization and sodification, excess nitrate in the soil solution, and contamination of the water table (World Health Organization - WHO, 2006; Dantas *et al.*, 2018).

Therefore, the maintenance of the sustainability of crops requires the monitoring of soil chemical, physical, and microbiological properties and the products originating from these areas, and the use of rotational strategies to avoid harmful levels of contamination.

Table 2: Contrast test for plant fresh weight (PFW), plant dry weight (PDW), 1000 achene weight (1000AW), capitulum internal diameter (CID), achene yield (AY), oil content (AOC), and oil yield (AOY) of sunflower plants of the Helio-250 cultivar irrigated with different depths (ID_1 and ID_2) of treated domestic wastewaters (DW_1, DW_2, and DW_3), and public water (PW_4).

Contrasts	PFW	PDW	CID	1000AW	AY	AOC	AOY
	F						
1 - DW_1× DW_2	1.49$^{n.s.}$	2.74$^{n.s.}$	2.69$^{n.s.}$	3.11$^{n.s.}$	9.67**	3.39$^{n.s.}$	13.71**
2 - DW_1× DW_3	0.27$^{n.s.}$	0.19$^{n.s.}$	2.21$^{n.s.}$	1.70$^{n.s.}$	6.06*	3.39$^{n.s.}$	7.89*
3 - DW_1×PW_4	73.69**	64.97**	8.67**	5.93*	15.04**	4.11$^{n.s.}$	18.92**
4 - DW_2× DW_3	0.49$^{n.s.}$	1.48$^{n.s.}$	0.23$^{n.s.}$	0.21$^{n.s.}$	0.42$^{n.s.}$	0.26$^{n.s.}$	0.79$^{n.s.}$
5 - DW_2×(DW_1 + DW_3)	1.23$^{n.s.}$	2.75$^{n.s.}$	1.07$^{n.s.}$	1.65$^{n.s.}$	4.70*	1.84$^{n.s.}$	7.03*
6 - PW_4×(DW_1 + DW_2 + DW_3)	126.02**	115.07**	23.86**	17.94**	49.34**	14.28**	63.79**
7 - ID_1×ID_2	2.46$^{n.s.}$	2.16$^{n.s.}$	0.65$^{n.s.}$	7.36*	4.35*	0.08$^{n.s.}$	4.63*
Treatments	**Means**						
	(g)	**(g)**	**(cm)**	**(g)**	**(Kg ha^{-1})**	**(%)**	**(Kg ha^{-1})**
DW_1	472	81.4	13.7	73.8	2769.2	36.1	1016.4
DW_2	516.5	91.5	15.0	83.1	3644.4	38.9	1415.5
DW_3	491	84.1	14.9	80.7	3462.2	38.2	1319.3
PW_4	159.6	32	11.3	61.1	1677.5	33	547.4
ID_1	389.6	69.1	13.5	79.7	3095.9	36.4	1156.7
ID_2	430	75.4	13.9	69.7	2680.7	36.7	992.64

* significant at 0.05 probability level; ** significant at 0.05 probability level; $^{n.s.}$ not significant at 0.05 probability level by the F test.

Table 3: Achene oil content (AOC) and 1000 achene weight (1000AW) of sunflower plants of the Helio-250 cultivar irrigated with different depths (ID_1, and ID_2) of treated domestic wastewaters (DW_1, DW_2, and DW_3), and public water (PW_4).

Treatments	1000AW		AOC (%)	
	ID_1	**ID_2**	**ID_1**	**ID_2**
DW_1	87.7 aA	59.9 bB	38.1 aA	34.2 aA
DW_2	81.3 aA	84.8 aA	39.9 aA	38.0 aA
DW_3	86.1 aA	75.3 aA	38.4 aA	38.0 aA
PW_4	63.6 bA	58.6 bA	29.3 bB	36.7 aA

Means followed by different uppercase letters in the columns, or different lowercase letters in the rows do not differ by the Skott-Knott test at 0.05 probability level.

CONCLUSIONS

The use of treated domestic wastewater for irrigation of sunflower plants increased achene yield and oil content; thus, it is an alternative to improve the crop production in regions with water scarcity;

The use of treated domestic wastewater provided significant gains in all variables evaluated when compared to the irrigation with public water;

The wastewaters treated by digestion decanter and anaerobic filtration (DW_2), and by anaerobic filtration (DW_3) provided higher achene and oil yields.

ACKNOWLEDGMENTS

The authors thank the National Council of Scientific and Technological Development CNPq for the financial support for this research.

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