Australian Journal of Crop Science AJCS

AJCS 16(04):479-487 (2022) ISSN:1835-2707
doi: 10.21475/ajcs.22.16.04.p3430

Nutrient balance in a constructed wetland system using treated domestic wastewater on ornamental sunflower crops

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Abstract

This study aimed to assess the nutrient dynamics of raw and treated wastewater (RWW and WW) in constructed wetlands (CW) for the irrigation of ornamental sunflowers, compared to freshwater (Fw) in Red Yellow Latosol (RYL) with (OF) and without (WF) inorganic fertilization. The study was carried out from July 10th to October 2nd of 2019. Wastewater was applied in pots with 10 kg of RYL. The amount of salts in the RWW, influent and effluent of CW and UnS (Uncultivated System), were evaluated in eleven samples. The study also assessed the following: plant height (PH), stem diameter (SD), number of leaves (NL), leaf area index (LAI), the inner diameter of the capitulum (IDc), the outer diameter of the capitulum (ODc), number of petals in the bud (NP), days after harvest (DAH), fresh phytomass in the aerial part (FPAP), dry phytomass in the aerial part (DPAP), fresh phytomass of the capitulum (FPc), dry phytomass of the capitulum (DPc), nutrient content in the aerial sunflower, and chemical composition in the RYL. The average removal efficiency of K^+, Ca^{2+}, and Fe in the CW was 34.33, 37.88, 39.82, and 45.40%, respectively. The PH (86.54 cm), SD (11.75 mm), NL (21), and LAI 3646.73 cm^2) were higher in the WWOF treatment at 70 days after sowing. Treated wastewater without fertilization (WWWF) presented higher P, K, S, B, and Mn absorption. Freshwater with fertilization accumulated greater amounts of N, and WWOF accumulated greater amounts of Zn. Wastewater increased the P content and decreased K^+ and Ca^{2+} in RYL. Irrigation with domestic WW in CW provided salts to the soil and increased the growth and quality of sunflowers irrigated with Fw.

Keywords: Biological treatment, emitters, irrigation, treated water, root zone system.
Abbreviations: RWW_raw wastewater; WW_treated wastewater; Fw_freshwater; RYL_Red Yellow Latosol; WWir_irrigation with wastewater; FwWF_freshwater without fertilization; FwOF_freshwater with fertilization; WWWF_treated wastewater without fertilization; WWOF_traditional wastewater with fertilization; PH _ plant height; SD_stem diameter; NL_ number of leaves; LAI_leaf area index; IDc_inner diameter of the capitulum; ODc_outer diameter of the capitulum; NP_number of petals.

Introduction

The decrease in the supply of freshwater appropriate for various human uses and the increase in demand from various sectors of the Brazilian economy has aroused the interest of public managers, private companies, and the scientific community in the use of low-quality water, such as domestic wastewater. Notably, it is an alternative water source (Rahav et al., 2017, Souza et al., 2020) because of the nutrients available for cultivated plants in the treated wastewater (Sandri and Rosa, 2017, Soothar et al., 2018), and the concern with the reduction of negative impacts due to the release of non-treated wastewater in surface and underground water sources.

When considered for irrigation (Angelakis and Snyder, 2015), wastewater reuse is beneficial, especially in crops not intended for dietary consumption. According to Garzón et al. (2017), several options have been developed for biological treatment and bioremediation of wastewater to transform these pollutants into less toxic or concentration-reducing pollutants that do not cause changes in ecosystems. For Zheng et al. (2020), CWs have become one of the preferred technologies to remove pollutants from wastewater due to low energy demand, low maintenance costs, and excellent ecological service values. However, wastewater containing organic materials and ammonium nitrogen can cause serious ecological problems if discharged into water bodies (Zheng et al., 2019).

Constructed wetlands have greater advantages compared to conventional treatments, such as those highlighted by Crespi et al. (2018): they are ecological systems that eliminate suspended solids, eutrophic organic attributes, pathogenic microorganisms, and toxic metals; as well, installation costs are lower than those of conventional treatment, and their implementation and maintenance are simple, which means reduced or energy-free consumption (Soler et al., 2019, Nivala et al., 2019).

The reuse of domestic wastewater treated by CW has great potential in the irrigation of several plant species (Angelakis and Snyder, 2015), such as the production of commercial flowers, which is a market in full expansion in Brazil. The ornamental sunflower is among the expanding and important species in the floriculture market. They are cut flowers and can be cultivated throughout the year due to their wide adaptability to various latitude, longitude, and photoperiod conditions.

Even with considerable nutrient content, irrigation with treated wastewater is not always sufficient to fulfill the nutritional demand of plants. Reuse has the benefits of use (Andrade et al., 2017), which may partially or fully meet the nutritional needs of sunflower crops and allow development and production levels equal to or greater than those achieved in traditional production systems (Costa et al., 2018). Therefore, there is a possible need for supplementation with synthetic fertilization to ensure their development.

For Schiavon et al. (2018), the chemical composition and accumulation of nutrients in sunflower leaves and fruit are essential information to know the species' nutritional requirements. This information can serve as a support to estimate how much of each nutrient needs to be supplied to plants through fertilization. For Bashir et al. (2021), the sunflower is a fast-growing plant and can remove contaminants from polluted soil and water.

In the crop of ornamental species, plant nutrition is essential for obtaining commercial quality flowers. According to Andrade et al. (2017), foliar diagnosis reflects the effects of soil-plant-climate interactions and cultural management. It is a tool to establish rational fertilization management, allowing the adequate supply of nutrients based on the quantitative variation in the nutritional content of the plant tissue. Souza et al. (2020) reported that ornamental sunflower production interests both producers and investors due to its high profitability, low area requirements, intensive production, and fast economic returns.

In this context, the study aimed to assess the nutrient dynamics from RWW, influent and effluent from ST and CW, development, biometric variables, nutrient contents in the aerial part of the ornamental sunflower, and chemical quality of the YRL, compared to Fw with and without inorganic fertilization.

Results and Discussion

Wastewater and freshwater attributes

The EC ranged from 808 to 1297 µS cm^{-1} in WW, with a significant difference only in Fw with 52 µS cm^{-1} (Fig. 1). Batista et al. (2018) observed EC of 823 µS cm^{-1} in ascending vertical subsurface CW. Sodium levels ranged from 45 to 102 mg L^{-1}, with efficiencies from 34.44 to 60.92%. Magnesium ranged from 29 to 129 mg L^{-1}, with efficiencies from 25.19 to 67.00, 76%, while Ca content ranged from 13.93 to 28.63 mg L^{-1}, with efficiencies from 1.19 to 64.53% (Fig. 1), lower than what was observed by Camacho-Ballesteros et al. (2020).

Dynamics of pH, P, K^+, Fe, and Ca^{2+} from raw wastewater to effluent used in sunflower irrigation

The pH in RWW was 6.9, decreasing to 6.3 in ECW, increasing again in the effluent of CW and UnS, 7.3 in UnS, 7.2 in CWP, 7.1 in CWT, and 7.5 in CWA, differing from ECW. Then, the composite mixture of CW and UnS was stored in a 5000 L reservoir, and a part was transferred to another 1000 L reservoir (WTPirri), from where it was captured for irrigation. The pH in the CW varied between 7.1 and 7.5, a range that favors the chemical precipitation of P associated with calcium compounds (Metcalf & Eddy, 1991). Phosphorus in RWW was 9.35 mg L^{-1}, being different in the following stages of the treatment, associated with a concentration of 28.63 mg L^{-1} of Ca_2^+ (Table 1).

When the experiment began, the soil pH was 5.9, but in the end, it varied between 5.1 and 5.3, without variations from one treatment to another. This behavior was also observed by Silva and Nascimento (2019) when evaluating the salinity impacts of three types of water, two of them being wastewater. The average P content in RWW was 9.35 mg L^{-1}, which is considered high, but in ECW, it decreased to 5.33 mg L^{-1}, with Ef of 41.10% in TS. The efficiency and average levels of CW and UnS were: UnS: 12.32%, (6.03 mg L^{-1}), CWP: 20.85% (5.70 mg L^{-1}), CWT: 11.60% (6.65 mg L^{-1}), and CWA: 16.80% (6.34 mg L^{-1}) (Table 1), respectively. There was a tendency to increase in each effluent compared to the influent. However, there was a reduction in the overall efficiency of TSE compared to RWW and WWir and raw wastewater effluent.

The overall P reduction in TSE was 34.30%, 20.85% in CWP, 11.60% in CWT, and 16.80% in CWA (Table 1), lower than the maximum efficiencies obtained by Avelar (2019), who reports an average Efs of total P removal in CW while being cultivated with the Mentha aquatic species (12.8 and 58.3%). Furthermore, according to Von Sperling (2005), the removal of P in CW for domestic wastewater treatment is less than 35%.

The P content in the effluent used in irrigation was 6.10 mg L^{-1}, while in the aerial part of the sunflower, it varied according to the type of treatment. Thus, the FwWF treatment was 32.17 mg L^{-1}, FwOF 36.25 mg L^{-1}, WWWF 40.55 mg L^{-1}, and WWOF 34.32 mg L^{-1}. Therefore, WWWF was the one that absorbed P the most, differing from the other treatments, while presenting data similar to the larger aerial part and capitulum fresh phytomass (Table 1).

Andrade et al. (2017) evaluated the fertilizer use with bovine manure and domestic TSE. Its application did not alter the P and K content of sunflower plants compared to water supply, with average values much lower than those obtained in this study.

At the beginning of the experiment, the P available in the RYL was 4.25 g kg^{-1} and increased to 6.63 g kg^{-1} in FwWF, 6.90 g kg^{-1} in FwOF, 6.80 g kg^{-1} in WWWF, and 6.76 g kg^{-1} in WWOF at the end of the sunflower cycle (Table 1). There was an increase in P concentration in all treatments.

Costa et al. (2018) verified the influence of texture, where soils with higher clay content have a lower P diffusion coefficient, partly explained by its higher P adsorption capacity, highly attributed to the presence and reaction with Fe oxides. In the RYL, there were high Fe indexes, ranging from 605.96 mg L^{-1} to 716.86 mg L^{-1}, which may explain the higher P absorption in all treatments (Table 1). Potassium ion (K^+) in RWW was 12.14 mg L^{-1}, reducing from 16.54 mg L^{-1} in ECW with an Ef. of 66%. In other words, there was an increase, where the values were: UnS = 33.8% (15.66 mg L^{-1}), CWP = 48.98% (12.70 mg L^{-1}), CWT = 4 5.94% (14.36 mg L^{-1}), and CWA = 44% (14.71 mg L^{-1}) (Table 1), and a total system efficiency of 37.8%.

The K^+ available in the RYL was 1.59 cmolc dm^{-3} at the beginning of the experiment and was reduced to 0.19 cmolc dm^{-3} for (FwWF), 0.31 cmolc dm^{-3} (FwOF), 0.54 cmol dm^{-3} (WWWF), and 0.81 cmolc dm^{-3} (WWOF) at the end of the sunflower cycle. There was a statistical difference between treatments, higher than WWOF followed by FwOF and WWWF treatments, and the lowest was the FwWF treatment (Table 1). There was less reduction in treatments irrigated with WWOF, possibly influenced by the input of TSE (10.15 mg L^{-1}) and the use of synthetic fertilization.

The K^+ content in the aerial part of the sunflower at the end of the cycle (70 DAS) in the FwWF treatment was 359.75 mg L^{-1}, FwOF 397.00 mg L^{-1}, WWWF 472.25 mg L^{-1}, and WWOF 428.75 mg L^{-1}. In other words, there was an increase in treatments using TSE. On the other hand, Andrade et al. (2017) irrigated with a water supply and the TSE, with K^+ concentrations of 5.43 mg L^{-1} in the water supply and 30.4 mg L^{-1} in the WW, and reported an increase of 40.95 mg L^{-1} K^+ for water supply treatments and 44.15 mg L^{-1} for TSE treatments in the aerial part of the sunflower at the end of the cycle, lower than those obtained in this study.

The total Fe content in RWW was 28.91 mg L^{-1}, and Ef in TS was 6.88%, while in the effluent of UnS, it was 44.21% (20.75 mg L^{-1}), CWP 61.71% (14.9 mg L^{-1}), CWT 62.42% (15.38 mg L^{-1}), and CWA 52.65% (18.63 mg L^{-1}). It had a statistical difference in beds, and CWP and CWT were lower in concentration than UnS and CWA. On the other hand, in the WWir, the total Fe content was 15.63 L^{-1}, a reduction of 45.40% after storage, and precipitation may have occurred inside the storage deposits regarding the effluent mixture of CWs and UnS (Table 1). Torres et al. (2017) report the removal of 66.67% of Fe in biological treatment systems using microalgae in domestic wastewater effluents.

Fe levels were observed in Fw of 0.97 mg L^{-1} and 15.68 mg L^{-1} in the WW (Table 1). There was no significant effect on the sunflower's aerial part, possibly due to the addition of fertilization in the soil and the low need for this nutrient by the plants. At the beginning of the experiment, the total Fe content in RYL was 73.4 mg L^{-1} and 667.53 mg L^{-1} at the end in the FwWF treatment. It was 716,86 mg L^{-1} in FwOF, 605.96 mg L^{-1} in WWWF, and 673.6 mg L^{-1} in WWOF treatment (Table 1), which is statistically superior to the treatments with fertilization, followed by the WWWF treatment. In the RYL, there were high Fe indices, which may explain the higher absorption of P in all treatments (Table 1). The total Fe content in the aerial part of the sunflower in the FwWF treatment was 5.07 mg L^{-1}, FwOF 4.18 mg L^{-1}, WWWF 5.36 mg L^{-1}, and WWOF 4.42 mg L^{-1}, being statistically superior in the WWWF and FwWF treatments without fertilization (Table 1).

The Ca^{2+} in RWW was 28.63 mg L^{-1}, reducing to 25.45 mg L^{-1} in ECW and Ef of 1.79% in TS. In UnS, Ef was 51.37% (17.36 mg L^{-1}), in CWP 57.39% (15.96 mg L^{-1}), in CWT 64.53% (13.93 mg L^{-1} 1), and in CWA 48% (20.20 mg L^{-1}), while in the WWir, after storage in a 5000 L container and then in another of 1000 L, it was 39.8% (18.00 mg L^{-1}) (Table 1). It demonstrates a greater reduction in Ca^{2+} levels in CW regarding UnS. As Ca^{2+} is essential for plants, in absolute value, the CW removed more regarding the UnS. However, there was a significant difference only in the CWT regarding the UnS. At the beginning of the experiment, the Ca^{2+} content in RYL was 4.53 cmolc dm^{-3}, and at the end, it was 3.30 cmolc dm^{-3} for FwWF treatment, 3.93 cmolc dm^{-3} for FwOF, 3.60 cmolc dm^{-3} for WWOF, and 3.86 cmolc dm^{-3} for WWOF. In other words, there was a reduction in all treatments, due to sunflower absorption, even if there were higher levels in treatments that received synthetic fertilization. Sandri and Rosa (2017) observed a variation in Ca^{2+} concentration in the soil between treatments with TSE applied by drip in the RYL layer from 0 to 0.2 m and a 60 to 200% variation compared to treatments irrigated with well water.

The Ca^{2+} in the aerial part of the sunflower in the FwWF treatment was 116.25 mg L^{-1}, in the FwOF 117.25 mg L^{-1}, in the WWWF 113.5 mg L^{-1}, and WWOF 111.25 mg L^{-1}. However, there was a significant difference between the sunflower part and RYL (Table 1). In RYL, a higher Ca^{2+} content was present in the fertilized treatments (OF) in both types of water compared to WF. In the aerial part of the plant, the highest concentration of Ca^{2+} occurred in treatments irrigated with Fw. The increase of Na in the adsorbed phase of the soil causes the displacement of divalent ions (Ca^{2+} and Mg^{2+}), which precipitate in the soil as Ca Ca^{2+} Mg $[(CO_3)^2]^2$, resulting in the formation of cemented thicknesses on its surface (Camacho-Ballesteros et al., 2020).

Biometric parameters of sunflower plants

Sunflower PH was higher in WWOF treatment at 15, 25, and 70 DAS, with an average of 6.82, 17.98, and 86.54 cm, respectively (Fig. 2), lower than those obtained by Raj et al. (2017) at 30, 60, and 90 DAS, which observed values of 84.4, 184.5, 224.7 cm, respectively, when intercalated with the application of Fw irrigation with effluent from the beverage industry. At 35 DAS, the WF had no statistical difference in the type of water. At 55 DAS PH, there was no statistical difference between WF and Fw. The only difference in the type of water was that WWOF was higher in this period, with 64.65 cm influenced by nutrients in higher concentration in WW.

The SD at 15, 25, and 35 DAS was higher in the WWOF treatment when compared to treatments irrigated with Fw, and the OF treatments were superior to WF for WW and Fw (Fig. 2). This was due to the contribution of nutrients by the TSE present in higher concentrations regarding Fw, especially phosphorus, nitrate, and calcium (Fig. 1). At 70 DAS, the SD was higher in the WWOF treatment (11.75 mm) than in the WWWF (10.78 mm), similar to those obtained by Silva and Nascimento (2019) when they used WW in the irrigation of Garden Dwarf Sunflower (*Helianthus annuus* L.) (10.95 mm). Oliveira et al. (2017) found that the increase in dosages of 0, 25, 50, 75, and 100% of TSE diluted in water supply resulted in higher rates in the SD of ornamental sunflower cv. Number of Leaves at 70 DAS was higher in WWOF treatment reaching 21 leaves. In the WWWF treatment, it was 19 leaves, and in the FWOF, 18 leaves (Fig. 2). In turn, Silva and Nascimento (2019) did not observe any difference in NL, and Oliveira et al. (2017) found higher NL at 35 days after thinning (DAD), at a concentration of 75% of WW.

Table 1. Values of pH, P, K^+, Ca^{2+}, and Fe in different locations of the wastewater treatment plant (WTP), in the soil and in the aerial part of the sunflower, and efficiency of removal of the attributes in the WTP.

Atribute dynamics									
WTP									
	pH	P (mg L^{-1})	Ef (%)	K^+ (mg L^{-1})	Ef (%)	Fe (mg L^{-1})	Ef (%)	Ca_2^+ (mg L^{-1})	Ef (%)
RWW	6.9 ab	9.35 a	-	12.14 ab	-	28.91 a	-	28.63 b	-
ICW	6.3 b	5.33 b	41.00	16.54 a	-66.00	25.85 ab	6.88	25.45 bc	1.79
UnS	7.3 a	6.03 ab	12.32	15.66 a	33.80	20.75 bc	44.21	17.36 bc	51.37
CWP	7.2 a	5.70 ab	20.85	12.7 a	48.98	14.90 c	61.71	15.96 bc	57.39
CWT	7.1 a	6.65 ab	11.60	14.36 a	45.94	15.38 c	62.42	13.93 c	64.53
CWA	7.5 a	6.34 ab	16.80	14.71 a	44.00	18.63 bc	52.65	20.20 bc	48.0
WWir	7.4 a	6.10 ab	34.33	10.15 b	37.88	15.63 c	45.40	41.72 a	39.82
RYL									
	pH	P (g kg^{-1})		K^+ (cmolc dm^{-3})		Fe (mg L^{-1})		Ca_2^+ (cmolc dm^{-3})	
IAS	5.9 a	4.25 b	-	1.59 a	-	71.10 c	-	4.53 a	-
FwWF	5.1 c	6.63 a	-	0.19 c	-	667.53 ab	-	3.30 b	-
FwOF	5.3 b	6.90 a	-	0.31 bc	-	716.86 a	-	3.93 ab	-
WWWF	5.3 b	6.80 a	-	0.54 bc	-	605.96 b	-	3.60 b	-
WWOF	5.3 b	6.76 a	-	0.81 b	-	673.70 a	-	3.86 ab	-
Aerial part of sunflower									
	pH	P (mg L^{-1})		K^+ (mg L^{-1})		Fe (mg L^{-1})		Ca_2^+ (mg L^{-1})	-
FwWF	-	32.17 d	-	359.75 c	-	5.07 a	-	116.25 a	-
FwOF	-	36.25 b	-	397.00 bc	-	4.18 b	-	117.25 a	-
WWWF	-	40.55 a	-	472.25 ab	-	5.36 a	-	113.50 b	-
WWOF	-	34.32 c	-	428.75 a	-	4.42 b	-	111.25 c	

RWW: raw wastewater collected before the entry of the first TS; ICW: effluent from the construct wetlands, which corresponds to the TS outlet; IAS: initial analysis of the soil present in the cultivation pots; in the treatments FwWF, FwOF, WWWF, and WWOF, both in the soil and in the aerial part of the sunflower, it was also analyzed at the end of the plant cycle. RYL: Red yellow latosol; WWir: wastewater used for irrigation and -: not carried out.

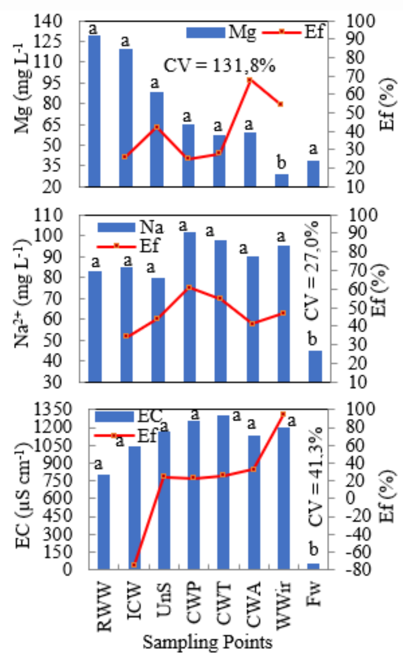

Fig 1. Average values of EC, Mg, Na, CV, and Ef and F test comparison of means between the points evaluated in the wastewater treatment plant and comparison with ware from the stream.

CV: coefficient of variation (%); RWW: raw wastewater; ICW: influent entry into CW and UnS; CWT: effluent from construct wetlands with cattail; CWP: effluent from the construct wetlands with Brazilian papyrus; CWA: effluent construct wetlands with water hyacinth; UnS: effluent from the uncultivated system; WWir: effluent wastewater treated; Fw: freshwater. Ef = efficiency between the affluent and the effluent of TS and CW and UnS (%).

Table 2. Average daily volume, difference between influent (I) and effluent (E) of the construct wetlands (CW) and uncultivated system (UnS) and values of potential evapotranspiration (PET).

UnS		CWP		CWT		CWA	
I	E	I	E	I	E	I	E
			Average daily volume (L)				
559.7	382.7	672.7	433.3	721.3	440.7	647.0	406.0
Dif.	PET	Dif.	PET	Dif.	PET	Dif.	PET
L day^{-1}	mm day^{-1}	L day^{-1}	mm day^{-1}	L day^{-1}	mm day^{-1}	L day^{-1}	mm day^{-1}
177.0	10.89	239.0	14.71	280.0	17.23	241.0	14.83
HRT (days)							
	6.6		5.4		5.09		5.6

I: Influent; E: effluent

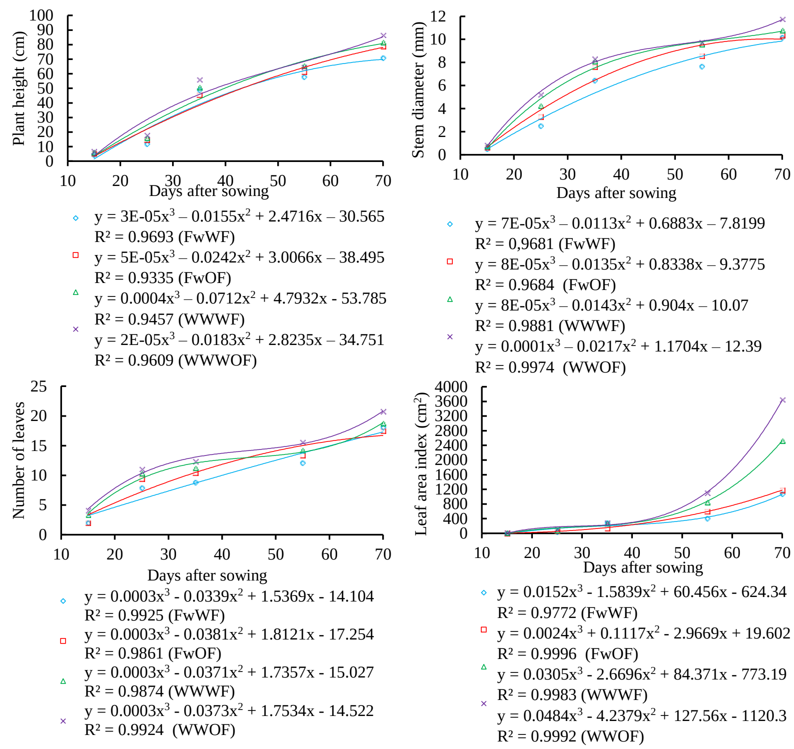

Fig 2. Plant height (PH), number of leaves (NL), stem diameter (SD) and leaf area index (LAI) of ornamental sunflower plants at 15, 25, 35, 55, and 70 days after sowing (DAS) irrigated with TSE and Fw in soil with fertilization (OF) and without synthetic chemical fertilization (WF).

Table 3. Chemical characteristics of Latosol red-yellow dystrophic at the beginning of the experiment.

pH	Ca_2^+	K^+	Mg_2^+	Al	AcPot.	TCC		Na^+
	cmol$_c$ dm^{-3}							
5.95	4.40	1.15	3.25	0.02	1.95	10.70		< 0.10
	g kg^{-1}			ppm			%	
P	TOC	OM	S	Fe	Zinco	Cu	V	
4.25	44.00	76.5	101.90	73.40	24.50	0.50	86.00	

TCC: Total Cation Capacity; TOC: total organic carbon; OM: Organic Material; V: Base Saturation; AcPot.: Potential Acidity.

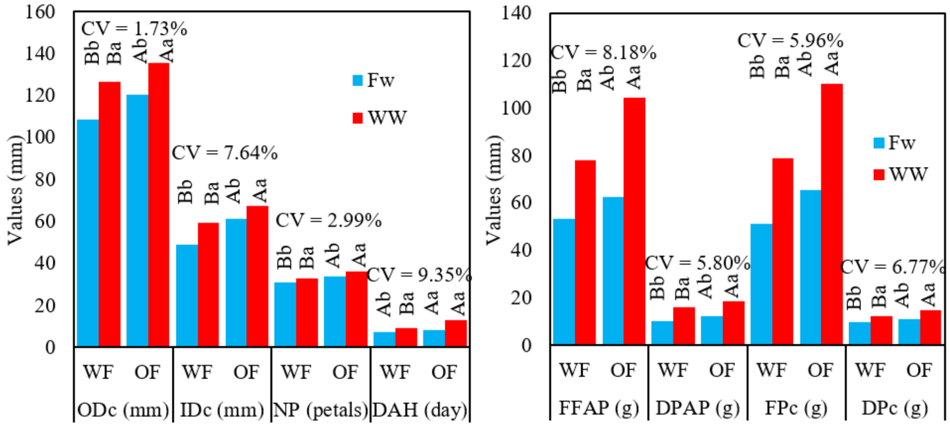

Fig 3. Outer diameter of the capitulum (ODc), inner diameter of the capitulum (IDc), number of petals (NP), days after harvest (DAH), fresh phytomass in the aerial part (FPAP), dry phytomass in the aerial part (DPAP), fresh phytomass of the capitulum (FPc), and dry phytomass of the capitulum (DPc) of ornamental sunflower plants at harvest in stage R6 (final flowering), irrigated with TSE and Fw in soil with fertilization (OF) and without synthetic chemical fertilization (WF). Uppercase letters in the lines and lowercase letters in the columns do not differ statistically from each other. CV: Coefficient of variation (%).

The LAI in treatments irrigated with TSE was higher regarding Fw at 15, 25, 55, and 70 DAS, with 20.74, 118.03, 1104.75, and 3646.73 cm^2, respectively. Similarly, the use of WWOF and FwOF was higher than WWWF and FwWF, demonstrating that the association of TSE and chemical fertilization provide higher FSA (Fig. 2). There was a significant difference between the treatment irrigated with TSE and FPAP in the FwOF and FwWF treatments, with an average of 53.03 g and 62.62 g, respectively. Sunflower FPAP and DPc were higher in the WWOF treatment, reaching 104.49 g and 18.54 g, respectively (Fig. 3). It is observed that CPD is directly associated with the use of WWOF, providing greater vegetative development. Thus, it increases the wet and dry phytomass of the aerial part and the sunflower capitulum.

It was observed that the IDc, ODc, NP, DAH, FPAP, DPAP, FPc, and DPc in the treatments irrigated with TSE were higher than those irrigated with Fw, and the FW was higher in the SA (Fig. 3). The highest phytomass indexes in treatments with TSE are due to the activity of organic matter, with the contribution of humic substances, which provides better conditions for the root system to develop. The same was observed by Oliveira et al. (2017), who found that the increase in dosages (0, 25, 50, 75, and 100%) of TSE diluted in water supply resulted in higher indexes of SD, NL, FPAP, DPAP, IDc, ODc and DPc.

Materials and Methods

Field trial

The research was carried out on the Água Limpa Farm (FAL) at the University of Brasília (UnB), at coordinates 15º 56' to 15º 59' S and 47º 55' to 47º 58' W. The average altitude is 1100 m and, according to Köppen's classification, it has an Aw climate (Alvares, 2013).

The evaluation of CW/FAL/UnB and the cultivation in pots of the ornamental sunflower, a hybrid sunflower, occurred from July to October 2019.

Wastewater was applied in 10 kg pots containing soil classified as a typical dystrophic Red-Yellow Latosol (Embrapa, 2013), Oxisol (Typic Haplustox) (Soil Survey Staff, 1998), or Gibbsic Ferralsol (FAO, 2015). It has a sandy texture, containing 4,1% sand, 36,7%, and 59,2% clay, and has a soil bulk density of 1 g cm^{-3}.

Generation, wastewater collection, and irrigation conditions

The raw wastewater came from toilets and the restaurant at FAL/UnB. The wastewater treatment plant (WTP) is comprised of three septic tanks, consisting of vinyl polychloride boxes of 5100 L each. Next, the influent was directed to a distribution box of 75 L, from which equal volumes were sent to the three constructed wetlands (CW) and an uncultivated system (UnS), arranged in parallel, with 6.5 x 2.5 x 0.5 m of length, width, and height, respectively, filled with gravel # 2, with a porosity of 48%, which results in a useful volume of 3.82 m^3 for each one. Furthermore, in one CW, cattail (*Typha spp*) (CWT) was cultivated; in another one, Brazilian papyrus (*Cyperus giganteus*) (CWP); in yet another, water-hyacinth (*Eichhornia crassipes*) (CWA); and lastly there was an uncultivated system (UnS) (control). Finally, the effluent mixture of CW and UnS was conducted to a reservoir with a volume of 4750 L and then pumped to another 1000 L reservoir. From there, it was then applied to sunflower irrigation (WWir) with an online dripper per pot, coupled in tubes of 12 mm external diameter, with a flow of 2.0 L h^{-1} at a pressure of 120 kPa, with an irrigation frequency of 2 days.

Sample collection

From July 10th to October 2nd of 2019, the influent and effluent samples were collected weekly in the WTP/FAL/UnB, as well as freshwater (Fw), totaling 11 collections. A subsample was collected at 8:00, 10:00, 12:00, 14:00, and 16:00 h, forming a composite sample of the collection day per assessed point. The collection sites were: the raw wastewater or influent of the TS (RWW), the effluent of the three TS, which is also the influent to the CW and UnS, the effluent of the CWT, CWP, CWA, and UnS, and the effluent applied in the irrigation after passing through a disc filter of 130 microns (an effluent mixture of the three CW and UnS). The blade applied throughout the sunflower cycle was 343.95 mm plot^{-1} of Fw and WW.

Samples chemical analysis

Samples were analyzed for electrical conductivity (EC), phosphorus (P), calcium (Ca^+), potassium (K), iron (Fe), and magnesium (Mg^{2+}) following the methodologies of Apha (2005). The efficiency (Ef) of the attributes evaluated in the influent and effluent of the TS, between the effluent of the CW and UnS, and the WWir was obtained by Equation 1, and between the influent and effluent of the CW and UnS by Equation 2.

$$\text{Ef}\ (\%) = \frac{\text{Co}-\text{Ce}}{\text{Co}}$$

Equation 1

$$\text{Ef}\ (\%) = \frac{(\text{Co x Qo})-(\text{Ce x Qe})}{(\text{Co x Qo})}$$

Equation 2

Where: Ef = efficiency of removing a certain attribute (%); Co = concentration of the attribute in the influent; Ce = Concentration of the attribute in the effluent; Qo = Flow of influent; and Qe = Flow of effluent.

The influent flow and effluent to CWT, CWP, CWA, and UnS was performed for 10 h (08:00 to 18:00) in three of the eleven days of sampling for physical, chemical, and microbiological analysis, allowing the registration of potential evapotranspiration (PET). The volumetric method was used with an 18 L graduated bucket, with a precision of 0.1 L and the aid of a digital chronometer. Whenever the 18 L volume was reached, the effluent was discharged into the corresponding CW or UnS. The influent from the CW was discharged into the 4750 L reservoir. The PET was calculated by: Volume (L)/CW or UnS surface area (m^2) (Table 2).

Experimental design

In sunflower cultivation, the experimental design was entirely randomized, with two types of irrigation water (WWir and Fw) in Red-Yellow Latosol (RYL) with (OF) and without (WF) inorganic fertilization, with six repetitions (pots), each containing four plants, totaling 24 parcels. The treatments were freshwater without fertilization (FwWF), freshwater with fertilization (FwOF), treated wastewater without fertilization (WWWF), and traditional wastewater with fertilization (WWOF).

The parcels consisted of a plastic pot with a volumetric capacity of 11 L, 27 cm of diameter, 24.5 cm of height, and a spacing of 0.6 m between pots and between rows, keeping a sunflower pot as a border throughout the experiment's perimeter. Fifteen days after sowing (DAS), a clearing of the excess of sunflower plants was performed, maintaining four plants per pot.

The experiment was conducted in a nursery with dimensions of 13 x 13 m, a height of 2.5 m, covered with screens that reduced solar luminosity by 50%. There was a plastic film of 150 micros with no lateral closure over it, and 11 g of Dolomitic Limestone Filler per 60 DAS pot was applied. Fertilization was applied in plots, mixing the fertilizers into the soil of each pot, with one application on the day of sowing and another 30 DAS, equivalent to 40 kg h^{-1} of N, 20 kg h^{-1} of P_2O_5, and 30 kg h^{-1} of K_2O, using urea (46% N), phosphate (21%), and potassium chloride (60%).

Soil chemical analysis

For soil chemical analysis, samples were collected during the experiment in 3 pots for treatment as follows: soil with fertilization and soil without fertilization (Table 2), then mixed in a container and fractionated into three subsamples comprising 500 g, totaling six samples.

At the end of the sunflower cycle, the soil was collected in four sites in the center of the soil surface radius in three pots per treatment, following the 0.00 to 0.15 m profile. It totals 12 soil samples, three for each treatment (FwWF, FwOF, WWWF, and WWA), using a riverside auger with a 7.5 cm diameter. Biometric analyses of sunflower were performed at 15, 25, 35, 55, and 70 DAS. The plant height (PH) was measured from the plant's neck to the apex bud, using an accurate 1 mm tape. The stem diameter (SD) measured with a digital caliper with a 0.01 mm accuracy at 2 cm from the soil surface. The number of leaves (NL), considering those with a minimum length of 2 cm and leaf area index (LAI), was estimated by the LAI Equation = 0.1328*C 2.5569, in which: C = The length of the leaf's central vein, and the final sum of the areas per leaf provides the plant's total leaf area (cm^2) (Maldaner et al., 2009).

Anatomical measurements

The following were measured: the inner diameter of the capitulum (IDc), the outer diameter of the capitulum (ODc), the number of petals in the capitulum (NP), days of harvest (CPD), fresh phytomass of the aerial part (FPAP), dry phytomass of the aerial part (DPAP), fresh phytomass of the capitulum (FPc), and dry phytomass of the capitulum (DPc) at stage R6 (final flowering) were measured. The ODc was obtained by the mean of horizontal and vertical measurements of the petal boundaries and from the arithmetic mean of the vertical and horizontal limits obtained in the disc flowers and NP by counting all petals without any discrimination criterion. For CPD, the duration of flowering was considered from the day on which all petals (ray flowers) fully opened until the end of stage R6. The wet mass of the four plants' aerial part of all useful pots was obtained on an electronic scale with a 0.001 g accuracy. The dry mass was obtained in a forced circulation oven at 65 °C for 48 h or until reaching a constant weight.

Histochemical analysis

The dry samples of the sunflower area part were crushed in a Wiley stainless steel mill to determine: P, K, Ca, and S (macronutrients) and B, Fe, Mn, and Zn (micronutrients). Acid solubilization (HNO_3:HCl, 3:1, v\v) was also performed. They weighed 0.5 g, and acid was added four times per treatment. Solubilization was performed in a microwave oven. Then, the content of the chemical attributes in the extracts was dosed in the optical emission spectrophotometer with an inductively coupled plasma source (ICP-OES). The ratio between the content of each nutrient and the sample's dry mass was used to measure how much of each nutrient accumulated in the aerial part. The Kjeldahl method obtained the total nitrogen content by digestion with sulfuric acid and hydrogen peroxide. Variance analysis was applied through the F test, followed by an analysis of mean comparison by the Tukey test at 5% probability, using the R program to analyze main the components of nutrients in the sunflower area.

Conclusions

The phosphorus, potassium, total iron, and calcium content were reduced in the effluent of the uncultivated system and constructed wetlands with cattail, Brazilian papyrus, and water-hyacinth. The height, stem diameter, number of leaves, and leaf area index of the sunflower plant were higher in the treatment with wastewater treated with inorganic fertilization. The capitulum's inner and outer diameter, the number of petals, days after harvest, fresh phytomass of the aerial part, dry phytomass of the aerial part, and the capitulum's fresh and dry phytomass in treatments irrigated with treated wastewater were higher than those irrigated with freshwater. Those irrigated with fertilized soil were higher than those without inorganic fertilization. At the end of the experiment, the potential of hydrogenics, calcium, and potassium in the soil decreased in all treatments, while phosphorus and iron increased.

Phosphorus and potassium contents in the aerial part of the sunflower were the ones that most correlated to the effluent treatment of wastewater without inorganic fertilization added to the soil.

Acknowledgments

To the National Council for Scientific and Technological Development-Brazil (CNPq), Notice MCTI/CNPq n. 14/2013, with contract number: 480332/2013-4 and the Federal District Research Support Foundation (FAPDF), Notice 03/2016 - Spontaneous Demand, Process No. 0193.001456/2016, for financial assistance.

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