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RESEARCH ARTICLE

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INTEGRATING VERTICAL FLOW CONSTRUCTED WETLANDS TO IMPROVE SEPTIC TANK AND STABILIZATION PONDS EFFLUENT QUALITY FOR RECYCLING WATER AND NUTRIENTS AT CHERRY TOMATO PRODUCTION

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ABSTRACT

The low rate of domestic sewage registered in cities in Latin America, the Caribbean, Asia, and Africa is the result of a centralized view, which does not allow access for all (decentralized), and which only uses conventional Sewage Treatment Plants to treat sewage without evaluating the potential for reuse and use of the by-products generated (sludge and gasses), adding value to them. Therefore, the objective of this study was to evaluate the efficiency of vertical flow constructed wetlands (VF-CW), as post-treatment of sewage (stabilization ponds and septic tanks) and to integrate it with the production of cherry tomatoes (*Solanum lycopersicum var. Cerasiforme*), by reusing the treated effluent. The purpose is to evaluate the processes and to allow a new business model. To study the cherry tomato production, VF-CW with coarse sand and part of the filtering medium composed of soil were evaluated, for a comparative agronomic study (plant adaptation), with 20 cm of soil and 40 cm of coarse sand. The effluents used were post septic tank (VF-CW-ST), and post stabilization pond (VF-CW-SP). The VF-CW received a hydraulic application rate of 170 $mm.day^{-1}$ and organic application ranging from 10-75 $gCOD.m^{-2}.d^{-1}$ and 10-60 $gBOD.m^{-2}.d^{-1}$. It was possible to verify that the VF-CW-ST and the VF-CW-SP with soil plus sand as a filtering medium, presented a worse performance in the removal of pollutants, although the plants reached the highest heights (75 cm). The VF-CW-ST with sand presented a better performance in the removal of pollutants, mainly to promote nitrification. Removal of: 89% of total nitrogen (TN) and 98% of ammoniacal nitrogen (NH4-N), post septic tank and 86% of TN and 93% of NH4-N, after maturation pond; 70% and 44% of BOD, post septic tank and maturation pond, respectively; 77% and 67% of phosphorus, post septic tank, and maturation pond, respectively; and 91% Turbidity for post septic tank and maturation pond. The load of pollutants, post septic tank, allows a greater supply of nutrients and organic matter that significantly influence the growth of plants. Tomatoes irrigated with water reached an average height of 40 cm, while those irrigated with effluent after maturation pond, 50 cm and with effluent post septic tank, 63 cm at the end of 75 days. Therefore, this is a viable option to avoid the use of mineral fertilizer and contribute to the fixation of carbon and nutrients in the soil and the production of biomass and food. The use of post septic tank VF-CW in (multi) single-family housing shows great potential for urban agriculture in a circular economy concept.

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INTRODUCTION

A study on Wastewater Treatment Plants (WWTPs) in six Latin American countries, showed that the most representative technologies in the region are stabilization ponds, activated sludge, and UASB reactors, representing 80% of WWTPs. Most technologies in Latin America treat small discharges (<25 $L s^{-1}$) moreover, smaller installations (<5 $L s^{-1}$) are widely applied in the region, and 34% of WWTPs are especially in Mexico and Brazil (NOYOLA *et al*, 2012). In the Brazilian scenario, according to the National System of Sanitation Information (SNIS), (SNIS, 2016) about 45% of the sewage generated in Brazil undergoes treatment, the other 55% are discharged directly into nature or have decentralized treatment (in the plot), however without proper supervision and regulation. According to the National Program by Household Sample (PNAD) published by the IBGE, in 2019 68.3% of the Brazilian population had access to the sewage collection network, i.e. access to the centralized network. Although there is a gap in proper access to sewage services, at the same time, Brazil is considered one of the main producers of food, fiber, and biofuels. Possessing approximately 12% of the planet's surface freshwater, playing a significant role in the world's agricultural production (FAO, 2017). Irrigation is the use that demands the most water in the country (ANA, 2015), the discharge used by the sector is 1270 m^3 s^{-1} and represents 54% of the total removed and 35% more than the consumed discharge in 2010. Irrigation, urban supply, industrial use, and animal watering are the uses that demand the most water resources in Brazil (FGV, 2016).

According to FAO (2013), the irrigated area in the world reached 310 million hectares and 70% of this total was located in Asia, which is equivalent to 35% of cultivated land in that continent. India is the country with the largest irrigated area in the world, with 66 million hectares, followed by China and the United States, with 62 and 27 million hectares, respectively. Worldwide, 61% of irrigation water use comes from surface water and 38% from groundwater (FAO, 2011). Based on this, the potential for expanding irrigated agriculture worldwide, estimated by FAO, is around 200 million hectares. However, the lack of treatment and pollution control makes the water, mainly the superficial, improper for consumption. This increases the cost of food, which is increasingly expensive, also as a result of climate change that affects crop productivity or the demands for increasingly expensive inputs and technologies. A possible solution for preserving these waters and guaranteeing water and even food security with irrigation is investing in sanitation and sewage treatment. Still, the reuse of this treated water needs to be envisaged. Yet, the design of these WWTPs is limited to the end of the treatment, but without reuse. This is due to their large, centralized structures, far from possible uses and which do not serve the entire population. That way, the use of simplified and decentralized technologies allows access to sanitation services in places with no collection networks where, often, it is not a viable option and could allow food production.

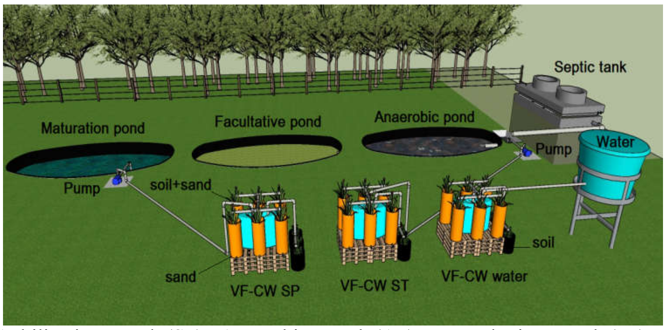
In this regard, constructed wetlands (CW), which are classified as solutions based on nature, are presented as an alternative, as they are of simple construction, low cost and with simplified operation and maintenance (KADLEC et al., 2008). CW is a type of sewage treatment process that began to develop in the 1970s (HATTERMANN et al., 2006; VYMAZAL et al., 2007), they are wetlands with roots that emerged as a way of simulating natural wetlands. Through the physical, chemical, and biological processes that occur in natural wetlands, they aim to purify wastewater (ZHI & JI, 2012; GROSSMANN, 2012). Aquatic macrophytes are commonly used in CWs. They play a role in pollutant removal (BRIX, 1997), in addition to reducing the clogging process (NIVALA et al. 2012; MATOS et al. 2015). Several studies report that macrophytes also favor the removal of nutrients (BRIX, 1997; GREENWAY, 2007; VYMAZAL, 2013). Many ornamental species have been used to provide the quality of wastewater treatment as well as to add aesthetics to these systems. However, the use of other types of plants can be a proposal not only to use nutrients by the species or to help in the treatment of effluent but also in agricultural production. This allows creating a business model for the Sewage Treatment Plants when using CWs, making them more sustainable, focusing on the production of biomass by the nutrients contained in the liquid part. Silva (2007) used rice (*Oryza L.)* as a crop in his VF-CW, providing average efficiencies of 97 to 99% of organic matter and 94 to 96% of nutrients, also improving soil quality and nutrient absorption by plants. According to Caselles-Osorio *et al.* (2018), domestic wastewater has been used as a source of fertilizer for agriculture or aquaculture, as it is rich in nutrients. Therefore, they evaluated a system with a septic tank, followed by a series of 5 subsurface horizontal flow CWs to evaluate the comparative efficiency of treatmentunits planted with tomatoes (*Lycopersicum sculentum*). Efficiency was about 41% for organic matter, 46 to 81% for coliforms, and Phosphorus elimination was 10%, with a relatively high production of tomatoes (730 g. m^{-2}). Given the above, the use of cherry tomatoes in vertical flow constructed wetland systems was not evaluated, and in addition to contributing to the performance of the system, it may be an option to reduce the use of water in this crop irrigation and add value to the WWTPs in a decentralized, single-family or condominium level with food production in urban or rural environments. Therefore, the objective of the study was to evaluate the efficiency of vertical flow constructed wetland systems in removing pollutants and the growth of the cherry tomato as an indicator of the development of this crop.

MATERIALS AND METHODS

The experiment was carried out in Brazil, at the Dom Bosco Catholic University Sewage Treatment Plant, located at the research base of a School Farm, in a tropical region, with coordinates: 20º26'34" S and 54º38'47" W, with 532 meters of altitude, the climate in the range between humid mesothermal without drought, presenting temperatures above 22°C in the drymonth and humid tropical climate with the rainy season in summer and drought in winter, with an average temperature between 19°C and 25°C (KÖPPEN & GEIGER, 1928). Vertical flow constructed wetland systems (VF-CW) were evaluated for 180 days, in the treatment of wastewater from the septic tank and stabilization ponds (both with more than 15 years of operation, presenting deficiencies in the treatment due to old projects and poor operation). Each VF-CW, on a mesocosm scale, has a diameter of 300 mm, a useful depth of 0.60 cm, and a filtering medium with coarse sand (d10 = 0,27 mm and uniformity coefficient of 2.19). The units with soil (20 cm soil on top and 40 cm sand) have the following characteristics: d10 = 0,05 mm and a uniformity coefficient of 9.4. All CW were planted with cherry tomatoes (*Solanum lycopersicum var. Cerasiforme*).

According to Figure 1, the VF-CW (A)'s structure that used only coarse sand as a filtering medium, was composed as follows: 5 cm of the free top layer, 5 cm of gravel (4.8 to 9.5 mm), 60 cm of sand, 5 cm of gravel (4.8 to 9.5 mm) and 5 cm of gravel 2 (32 to 25 mm), operating in a downward flow. The VF-CW (B) has a similar assembly, except that part of the filtering medium is soil, with 20 cm of soil under 40 cm of sand. To carry out the experiment, 4 (four) VF-CW mesocosms were used, 2 with coarse sand filtering medium, one to treat effluent post septic tank, and another for effluent post stabilization pond. The same occurred with the filtering layer composed of sand plus soil, with another 2 (two) VF-CW, one for septic tank and another for stabilization pond. The VF-CW (1) received an effluent post septic tank, while the VF-CW (2) received an effluent post stabilization pond. The VF-CW (3) received only water, as they served as an (agronomic) standard to verify the growth of the crop used, in relation to wastewater. The entire study system, as shown in Figure 1, was connected through a distribution system made with PVC pipe with a diameter of ½'. After the biofilm establishment period, the VF-CW units operated in a hydraulic regime with a hydraulic loading rate (HLR) of 170 mm d-1 (9 pulses per day). As for the organic loading rate (OLR), it was 52 g COD.m^{-2}.d^{-1} for the VF-CW in the post septic tank effluent treatment and 48 g COD.m^{-2}.d^{-1} for the VF-CW in the treatment of effluent from the stabilization pond.

Agricultural Experimentation: The study with the cherry tomatoes had 27 seedlings of the culture. Initially, the seeds were planted in a sowing pot with a commercial substrate composed of pine bark. In a greenhouse, the seeds were daily irrigated for 25 days and then transplanted to the VF-CW and plastic containers. During this process, weekly doses of calcium nitrate were applied, in the proportion of 5g of the reagent for 1 liter of water, to assist in the structure of the plant. The experimental design was 3x3 (3 types of soil and 3 types of irrigation), with 3 replications, totaling 27 sampling units. The 3 soil types were: sand only, sand plus soil, and soil only (used as a default).



Stabilization pond (SP): Anaerobic Pond (AP) + Facultative Pond (FP) + Maturation Pond (MP); VF-CW SP: vertical flow constructed wetland for stabilization pond effluent treatment; VF-CW ST: vertical flow constructed wetland for septic tank effluent treatment

Figure 1. Representation of the different configurations for the stages of the study

The 3 types of irrigation were: effluent post septic tank treated by VF-CW, effluent post stabilization pond treated by VF-CW, and water (used as default). Treatments with sand and sand plus soil were performed using VF-CW mesocosms. However, as can be seen in Figure 1, plastic containers of 33 dm³ were used, with only substrate soil, to verify the growth of cherry tomatoes without the interference of the VF-CW structure. In the same way that there were different effluents for treatment in the CWs, three of these systems received only water for irrigation (Figure 1), because water is used as a default, being the conventional method of cultivation, i.e. without treated effluent, and reuse. This same variation of liquid effluent was carried out in the plastic containers, therefore, containers C1 received effluent post septic tank, C2 received effluent post stabilization pond, and C3, water, for this last condition, these also served as an agronomic default to evaluate the growth.

Agricultural Experimentation: To evaluate the performance of the VF-CWs in pollutant removal efficiency, we carried out an analysis of E.coli (Escherichia coli), Total Coliforms (TC), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Nitrogen (TN), Total Kjeldahl Nitrogen (TKN), Ammoniacal Nitrogen (NH4-N), Nitrite (NO2-), Nitrate (NO3-), Solids (Total - TS, Dissolved - TDS, Suspended - TSS), Color, pH, and Turbidity recommended according to Standard Methods for the Examination of Water and Wastewater (APHA, 2014). Soil chemical analysis was performed according to Cardoso (2009), adapted by Mangelo (2014). The analyzed parameters were: Organic Matter (Modified South Dakota Method), Potential Acidity (Hydrogen + Aluminum), Calcium, Magnesium and Aluminum, Phosphorus, Potassium, pH (H2O e CaCl2). Table 1 provides the characterization of the filtering medium. For the monitoring of the cherry tomato seedlings, the plant height was measured in each planted unit, which is determined from the vertical distance between the soil surface (CUNHA et al. 2014). Tukey's tests with a significance level of 5% were performed to compare the concentrations of physicochemical and microbiological parameters, as well as to compare the data collected on the growth of the cherry tomatoes, as the data follow a normal distribution.

RESULTS AND DISCUSSION

Assessment of the constructed wetlands: Table 2 presents the concentration values of the input and output of the systems of the evaluated parameters (COD, BOD, TKN, N-NH4, $NO2^-$, $NO3^-$, P, TS, total coliforms, and E. coli) and the statistical analysis of performance comparison between systems. Figure 2 shows the efficiency of the system by calculating the removal percentages of each VF-CW studied.

Carbonaceous organic matter (BOD and COD): Based on the results obtained, it was possible to observe that for BOD when comparing the efficiency of the VF-CW-ST and VF-CW-SP to the filtering medium (only sand and sand plus soil), for each effluent used (post septic tank and stabilization pond), the systems were statistically equal in their removals and did not present variation. Yadav et al. (2018), evaluated a vertical flow system to treat domestic wastewater in India, with two plant species: *Typha angustata* and *Canna indica*, in this study they obtained 65% removal in BOD with an application rate of 150 mm.d-1 and 62% with an application rate of 225 $mm.d^{-1}$. These results were similar to the systems studied here with an application rate of 170 $mm.d^{-1}$ in the VF-CW-TS, reaching averages of 70% and 73% with sand and sand plus soil filter media respectively.

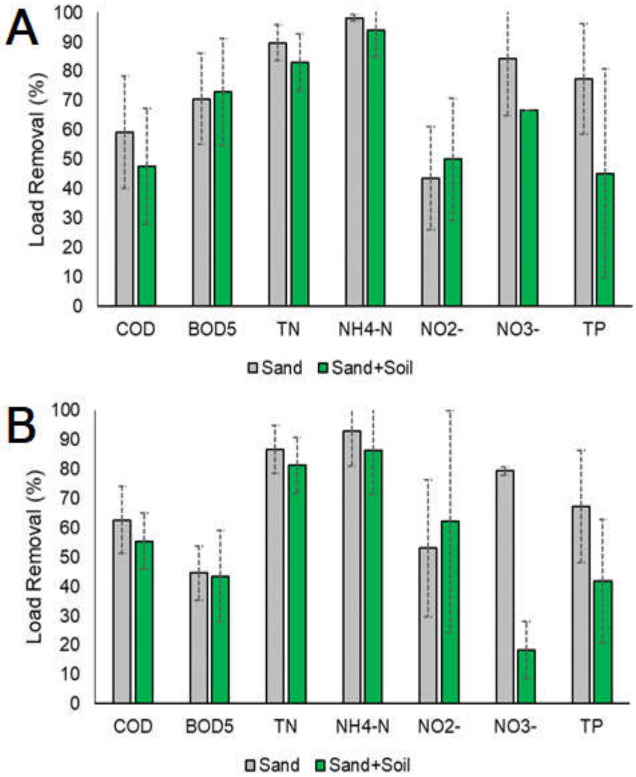


Figure 2. Removal percentage of the evaluated parameters, A: VF-CW-ST; B: VF-CW-SP

It is worth noting that according to the Conama Resolution No. 430, to release effluents directly into a receiving body, a minimum removal of 60% of BOD is required (CONAMA, 2011). Based on this, it is noted that the use of cherry tomato (*Solanum lycopersicum var. Cerasiforme)* does not interfere negatively when compared with the most common macrophytes. Even with a higher application rate, and even with the addition of soil to the system, although in the long term it is known that soil can accelerate the clogging process, it is not indicated. In this study, land use was only used for an agronomic evaluation. For COD, the VF-CW-ST reached removals of 60 and 48% for the sand and sand plus soil filtering medium, respectively. For the VF-CW-SP, the removal percentages were 63 and 55%. Concerning the filtering medium, there was no statistical difference, although the percentage is higher for only sand. Hu et al. (2016), in their study with VF-CW in the treatment of urban wastewater, reached 83-88% removal for COD when applied a lower loading of 2.5 $g.m^{-2}.d^{-1}$.

Phosphorus and Nitrogen: The average efficiencies of Phosphorus were higher in the VF-CW (A) systems according to the statistical analysis. They were 78% for VF-CW-ST and 67% for VF-CW-SP. The soil used is endowed with more nutrients than the sand, as shown in Table 1. Therefore, this factor can influence the results found in the VF-CW (S+S) systems, as 20 cm of the filtering medium layer is soil. In these systems, removals were lower, reaching 45% for VF-CW-ST and 42% for VF-CW-SP. Trein et al. (2015), showed 61% of removals for TP in a VF-CW system with coarse sand, used as post-treatment of an anaerobic reactor with effluent and commercial activity. As for a VF-CW with a saturated bottom as a treatment for domestic effluent, the removal of this parameter was 93%, according to Trein et al. (2015), this high Phosphorus removal was provided by chemical adsorption in the filter material, which was coarse sand since it is the predominant removal mechanism of orthophosphate. In the removal of TKN, it was verified that the VF-CW (S+S) systems, both for effluents post septic tank and stabilization pond, presented statistical differences when compared to the VF-CW (A) systems. The removal percentages in the VF-CW-ST were 90 and 83% for sand and sand plus soil, respectively. For VF-CW-SP, they were 87 and 91%, and it is possible to verify that the nitrification process occurs, both for the system and post-treatment of the stabilization ponds, as well as the post septic tank. According to Pelissari et al. (2013), one of the main factors that contribute to the occurrence of nitrification, in addition to the good adaptation of the nitrifying microbiota, is the effective transfer of oxygen in the filtering mass, due to intermittent feeding. Hu et al., (2016) divided their experiment with VF-CW into two groups: without plants and with *Canna indica L.* The maximum efficiencies of TKN and NH4+ removal in the systems without plants were 70.3% and 79.8 % and for planted 87.5% and 92.5%. Similarly, for the VF-CW post septic tank and post stabilization pond, the removals were on average 86% and 83% for sand and sand plus soil filtering medium, respectively. Yadav et al. (2018) observed that the TN removal efficiency for a VF-CW with *Typha angustata* was 60%, while for the VF-CW with Canna indica the average removal was 77%, and in both cases, the application rate was 150 mm d^{-1}, similar to that applied in this study, which was 170 mm d^{-1}. Thus, we can observe that with a higher application rate, even with *Solanum lycopersicum var. Cerasiforme* it is possible to reach removals that are satisfactory and superior to the studies cited.

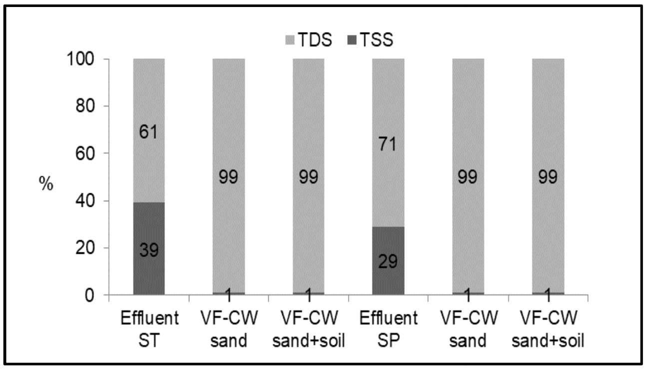


Figure 3. Total, suspended, and dissolved solids percentage distribution in the raw effluent and post the constructed wetlands treatment

Turbidity, total coliforms, and E.coli: The turbidity values at the output were on average 3.24 NTU and 6.49 NTU in the VF-CW (A) systems with post septic tank effluent and stabilization pond effluent, respectively. This indicates the possibility of these systems being used as a pre-treatment for later solar disinfection (SODIS). Along with the averages of 3.75 NTU and 7.33 NTU in the VF-CW (A) systems with post septic tank effluents and stabilization pond effluent, respectively. According to the literature, the ideal value to promote solar disinfection is 30 NTU, according to the SODIS Manual (EAWAG, 2016). The analyzes performed showed decay in relation to total coliforms and E. coli with the removal of 2 to 3 logarithmic places. The World Health Organization (WHO, 1989) recommends microbiological guidelines for the use of sewage in agriculture. Within these guidelines, the removal achieved in the VF-CW fits into categories A and B (irrigation of cereals, industrial crops, forage, pastures, and trees, in the risk group: workers). It was possible to verify that the effluent of the system composed of the septic tank and VF-CW has a result in 7 logarithmic places. The effluent from the system composed of stabilization ponds, with maturation for disinfection and VF-CW as post-treatment, obtained 6 logarithmic houses. According to Sperling (2005), to achieve efficiency in the removal of coliforms in anaerobic and facultative ponds, values between 60 - 99.99% (4 logarithmic places) must be obtained, i.e. the system was above the recommended level.

Solids: The total solids (TS) were the parameter with the lowest removal efficiency. Figure 3 shows the average distribution of suspended and dissolved solids across all systems. The effluents before treatment were initially with a higher percentage of dissolved solids (TDS) and it was possible to verify the increase in each unit of VF-CW. Figure 2 shows the behavior of the solids between the systems. When analyzing the parameter of total solids, it was verified that the VF-CW (S+S) systems for both effluents post septic tank and stabilization pond, presented statistical difference when compared to the VF-CW (A) systems. The systems with sand and soil filtering medium showed a lower retention capacity of total solids from the effluents used. There was an increase in the amount of TDS in all VF-CW systems at the same time that occurred a decrease in TSS. According to Morel & Diener 2006, the non-removed TDS fraction may be related to the non-biodegradable COD fraction due to inorganic and colloidal substances present in cleaning and personal care products.

Analysis of applied and removed organic loadings: Figure 4 shows the values of applied organic loading and removed organic loading for the COD, BOD, TP, TN, and NH-4, parameters.

Organic Loading (BOD and COD): For the COD parameter, the VF-CW-ST with and without soil, the maximum applied organic loading was approximately 75 $g.m^{-2}.d^{-1}$, however, the VF-CW without soil obtained the removal of approximately 60 $g.m^{-2}.d^{-1}$ while the VF-CW with the soil removed about 50 $g.m^{-2}.d^{-1}$. In the VF-CW-SP with and without soil, the maximum applied loading was approximately 60 $g.m^{-2}.d^{-1}$, with removals of 40 and 35 $g.m^{-2}.d^{-1}$, respectively. Sousa et al. (2004) applied lower loadings, ranging from 5.01 to 9.45g COD. $m^{-2}.d^{-1}$ with a removal efficiency between 70 to 86%. Bohórquez et al. (2016), evaluated domestic wastewater showing average removal rates of 48 and 24 g g $m^{-2}.d^{-1}$ of COD; 35 and 16 g $m^{-2}.d^{-1}$of BOD. Pelissari et al. (2015), applied an average load of 317 g $COD.m^{-2}.d^{-1}$ with an average efficiency of 68%, in terms of concentration, given that one unit received approximately 2 times more loading than the design parameter, which followed recommendations of Winter & Goetz (2003), who established a maximum loading limit of 140 $g.m^{-2}.d^{-1}$. Therefore, the system proposed here proved to be efficient in removing applied loadings, presenting removals similar to those mentioned above, both for applied loadings lower than the one studied, and for higher loadings. Regarding the applied loadings of BOD, the VF-CW-ST showed the same behavior, regardless of the filtering medium, receiving loadings close to 60 g $m^{-2}.d^{-1}$ and removing approximately 50 $g.m^{-2}.d^{-1}$. However, when the system is used as a post-stabilization pond treatment, regardless of the filtering medium, the system received between 10 to 15 g $m^{-2}.d^{-1}$ and removed between 8 to 10 g $m^{-2}.d^{-1}$, i.e., lower loadings due to the better performance of the stabilization ponds in relation to the septic tank.

Total Phosphorus Loading: For Total Phosphorus, regardless of the type of effluent, the applied loadings varied from 0.1 to 0.9 $g.m^{-2}.d^{-1}$. However, post stabilization pond, the values are concentrated between 0.1 and 0.5 $g.m^{-2}.d^{-1}$. It was possible to observe that for the VF-CW with the two effluents, with sand, almost all of the applied loading was removed. However, for the system with soil, due to the smaller amount of sand for adsorption and due to the already present values of Phosphorus in the composition of the soil used, the same performance did not occur. Pelissari et al. (2015), applying a higher loading, with an average of 7.35 g P. $m^{-2}.d^{-1}$, reached a low removal, which, according to the authors, occurred since the beginning of the monitoring, reaching percentages of removals in the 10% range. The evaluation was carried out with a VF-CW with a surface area of 14.3 m² with the macrophyte *Typha domingensis Pers.*, operating under a hydraulic regime of 4,5 $m3.week^{-1}$. Sousa et al. (2004) applied between 0.15 to 0.22 g P. $m^{-2}.d^{-1}$, values that are similar to the loadings applied in this study.

Table 1. Physicochemical characteristics of the soil and sand used in the experiment

Identification	pH		MO	P	K	Ca	Mg	Ca+Mg	Al	H	H + Al	T	V
	H_2O	$CaCl_2$	g/dm³	mg/dm³				$cmol_c/dm^3$				%	
Sand	7,59	7,35	2,0	1,50	0,03	0,15	0,45	0,60	0	0	0	0,6	100,0
Sand MP	5,18	4,55	1,54	19,42	0,03	-	-	0,85	0,15	1,16	1,31	2,19	40,18
Sand ST	5,58	4,95	1,18	18,76	0,02	-	-	0,65	0,00	0,73	0,73	1,40	47,86
Soil	6,38	7,01	130,0	38,85	0,36	8,90	6,8	15,7	0,0	3,65	3,65	19,65	81,6
Soil ST	6,9	6,30	135,25	832,70	0,28	16,40	0,85	17,25	0,00	2,55	2,55	20,08	87,30
Soil MP	5,84	5,24	139,54	747,19	0,24	12,95	0,80	13,75	0,00	6,57	6,57	20,56	68,04

Table 2. Results of physicochemical and microbiological parameters

VF-CW-ST						
	Temperature (ºC)	pH	BOD (mg L^{-1})	COD (mg L^{-1})	TP (mg L^{-1})	TN (mg L^{-1})
Effluent	25,6 ± 2,69 a	6,97 ± 0,40 a	176,43 ± 94,91 a	289,42 ± 134,61 a	3,28 ± 1,54 a	15,12 ± 8,74 a
Sand VF-CW	24,3 ± 5,04 a	6,95 ± 0,78 a	46,29 ± 30,98 b	105,09 ± 58,17 b	0,51 ± 0,31 ab	1,82 ± 1,90 b
Sand + soil VF-CW	24,1 ± 4,78 a	6,57 ± 0,45 a	40,46 ± 25,56 b	135,61 ± 61,50 b	1,37 ± 0,63 b	2,89 ± 2,90 b
NH4-N (mg L^{-1})	NO_2- (mg L^{-1})	NO_3- (mg L^{-1})	Turbidity	TS (mg L^{-1})	*E.coli* (NMP/100ml)	TC (NMP/100ml)
8,36 ± 3,38 a	0,14 ± 0,17a	0,94 ± 0,40 a	46,57 ± 33,11 a	334,83 ± 61,63 a	2,50E+07 ± 2,79E+07 a	2,79E+07 ± 3,14E+07 a
0,34 ± 0,40 b	0,095 ± 0,12 a	0,11 ± 0,12 b	3,24 ± 2,63 b	246,38 ± 28,62 a	3,00E+05 ± 6,76E+05 b	1,70E+05 ± 4,61E+05 b
0,38 ± 0,36 b	0,085 ± 0,11 a	0,31 ± 0,14 b	6,49 ± 3,53 b	298,67 ± 46,86 a	4,25E+05± 8,93E+05 b	1,10E+05 ± 1,80E+05 b
VF-CW-SP						
	Temperature (ºC)	pH	BOD (mg L^{-1})	COD (mg L^{-1})	TP (mg L^{-1})	TN (mg L^{-1})
Effluent	23,0 ± 2,37 a	7,42 ± 1,65 a	240,10 ± 229,29 a	296,37 ± 159,16 a	2,03 ± 1,54 a	11,32 ± 10,76 a
Sand VF-CW	23,0 ± 1,71 a	6,63 ± 1,00 b	115,55 ± 75,30 b	107,09 ± 54,61 b	0,46 ± 0,25 b	1,99 ± 2,72 b
Sand + soil VF-CW	23,2 ± 1,94 a	6,40 ± 0,94 b	129,68 ± 92,10 b	130,37 ± 68,98 b	0,97 ± 0,34 b	2,82 ± 3,42 b
NH4-N (mg L^{-1})	NO_2- (mg L^{-1})	NO_3- (mg L^{-1})	Turbidity	TS (mg L^{-1})	*E.coli*(NMP/100ml)	TC (NMP/100ml)
3,14 ± 1,04 a	0,32 ± 0,00 a	0,71 ± 0,07 a	57,49 ± 47,10 a	347,00 ± 176,00 a	7,79E+07 ± 1,18E+07 a	2,32E+08 ± 2,55E+07 a
0,17 ± 0,28 b	0,08 ± 0,03 a	0,15 ± 0,02 b	3,75 ± 3,71 b	204,33 ± 59,34 a	1,30E+05 ± 1,31E+05 b	5,30E+05 ± 6,06E+05 b
0,32 ± 0,32 b	0,05 ± 0,01 a	0,15 ± 0,02 b	7,33 ± 8,57 b	249,50 ± 88,13 a	2,89E+05± 5,34E+05 b	1,34E+05 ± 2,11E+05 b

The removals achieved by these authors were between 82 and 90%, also similar to the concentrations studied here with removal percentages of 94% and 90%, post septic tank and stabilization pond, respectively, both with only sand with filtering medium.

Total Nitrogen Loading: The maximum applied loadings of TN for all VF-CW-ST were approximately 5 $g.m^{-2}.d^{-1}$. with removal close to this value. For all VF-CW-SP, the applied loadings were concentrated between 0.03 $g.m^{-2}.d^{-1}$, reaching approximately 4 $g.m^{-2}.d^{-1}$, with similar removals from the applied values. Thus, it was possible to verify that there was no statistical difference for this parameter (Table 2), regardless of the effluent and filtering medium. The same occurred for NH4+, regardless of the effluent and filter medium, this parameter showed no statistical difference in its removal concentrations. Bohórquez et al. (2016) evaluated a VF-CW in the treatment of domestic wastewater and showed that sand beds were significantly more efficient than gravel in removing Ammoniacal Nitrogen, reaching 7 $g.m^{-2}.d^{-1}$, reaching a removal of 77%. The loadings applied in the present study for the VF-CW-ST, regardless of the filtering medium, were approximately 30 $g.m^{-2}.d^{-1}$, with almost total removal of this loading. As for the VF-CW-SP in all filtering mediums, the loadings applied were 0.7 $g.m^{-2}.d^{-1}$. (lower due to nitrification in the stabilization ponds), and they were almost entirely removed, and with that, the removal percentages averaged 96% for VF-CW (A) and 90% for VF-CW (S+S).

Cherry tomato growth assessment: The development of the used culture was evaluated to verify if the system with soil provided better growth for the cherry tomato. In Figure 5, one can observe the development of the plants in relation to the filtering medium used, where it was possible to verify that the plastic containers with soil provided a greater development for the plant, after all, they were in ideal conditions of fertilization and water. The VF-CW composed of sand plus soil showed higher growth than sand. The soil used in the systems is endowed with more nutrients than the sand, according to Table 1, which justifies the difference in the development of cherry tomatoes in different types of filtering mediums. Among the data collected, there is a significant difference in the amount of phosphorus, potassium, calcium, and magnesium, important elements for plant growth. Lopes (2009) states that in addition to promoting the formation and premature growth of roots, phosphorus improves water use efficiency, when at a high level in the soil, it helps to maintain its absorption by seedlings, even under high tension conditions of soil moisture. Based on the analysis carried out to characterize the sand and soil, the soil presented an average of 38.85 mg dm^{-3} of phosphorus while the sand 1.50 mg dm^{-3}. That way, the nutrients in the soil filtering medium contribute to the better development of the plant, as it is a fertilized soil, this factor contributed to the growth of one system in relation to the other. The plants irrigated with effluents post septic tank had a greater development in relation to the effluent from the stabilization pond, as well as the plants that received effluent from the stabilization pond showed greater growth in relation to irrigation with water. Based on the analysis carried out, it was found that the effluent post septic tank has more nutrients and organic matter than the effluent from the stabilization pond. According to Augusto et al. (2003), Hussar et al. (2005), and Caselles-Osorio et al. (2018), the use of wastewater as an alternative for water and nutrients showed similar results with adequate growth for the plants studied. Augusto et al. (2003), obtained satisfactory results studying the production of seedlings of *Croton floribundus Spreng*. (Capixingui) and *Copaifera langsdorfii. Desf.* (Copaíba) in an irrigation system with wastewater resulting from the biological treatment of sewage. Hussar et al. (2005) used swine manure effluent in beet fertigation, in which the use of treated effluent provided higher NPK (Nitrogen, Phosphorus, and Potassium) content for the crop. Caselles-Osorio et al. (2018) evaluated tomato production in horizontal flow constructed wetlands units as post septic tank treatment, obtaining positive results in pollutant removal and high productivity for the culture. In addition to verifying which system provided the best growth of the cherry tomatoes, the variation between treatments with water and effluent for irrigation was evaluated, enabling a comparison in plant development between the systems. There was a significant effect between the types of effluents used, from 45 days after planting. Water in irrigation is used as a default (witness) to compare growth in relation to irrigation performed with domestic sewage effluent. Based on the average variations, at the end of 75 days after planting, tomatoes irrigated with effluent from the stabilization pond showed 9.6 cm more than tomatoes irrigated with water. Regarding the post septic tank

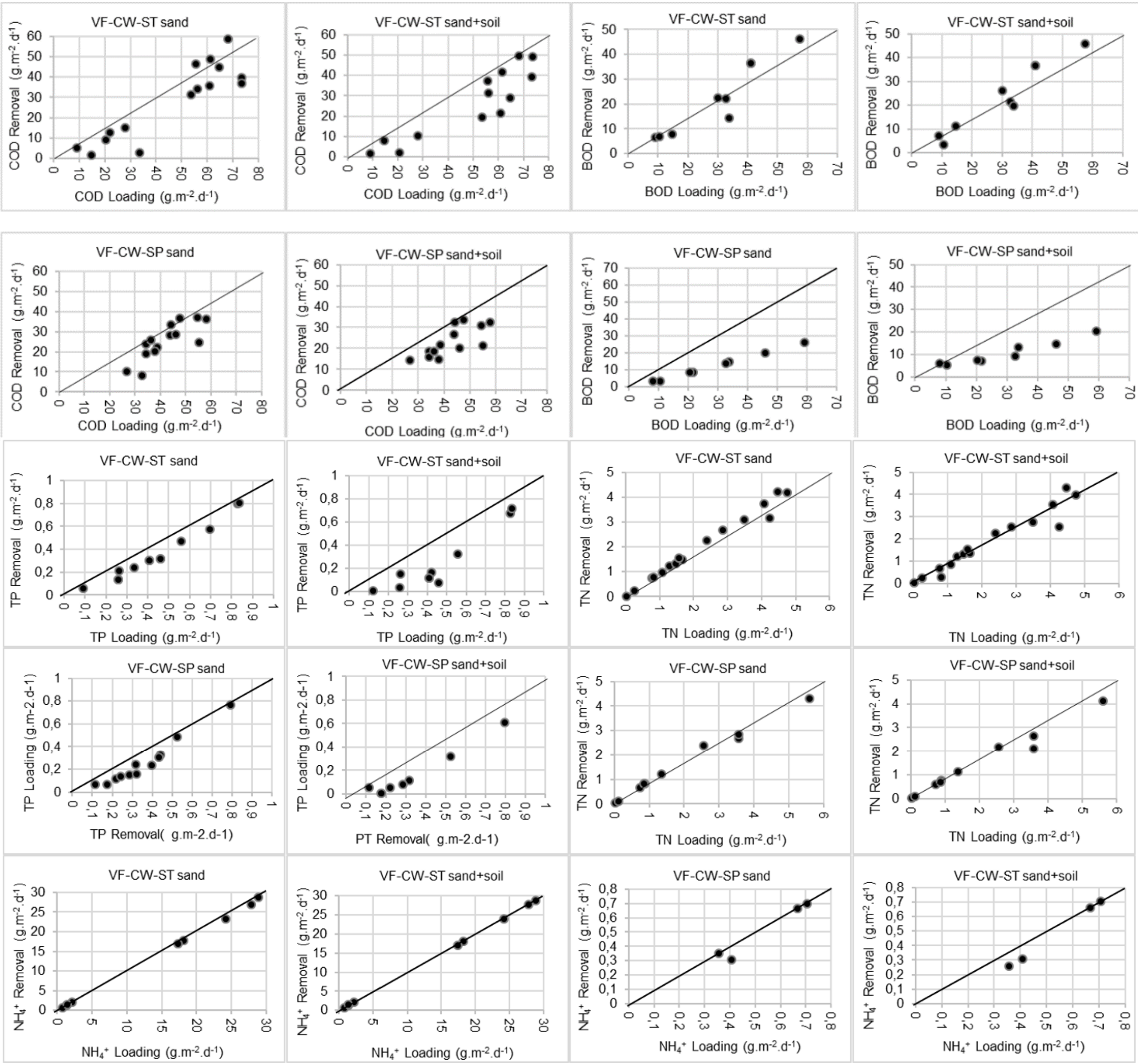


Figure 4. Applied organic loading and removed organic loading values for the parameters COD, BOD, TP, TN, and NH-4

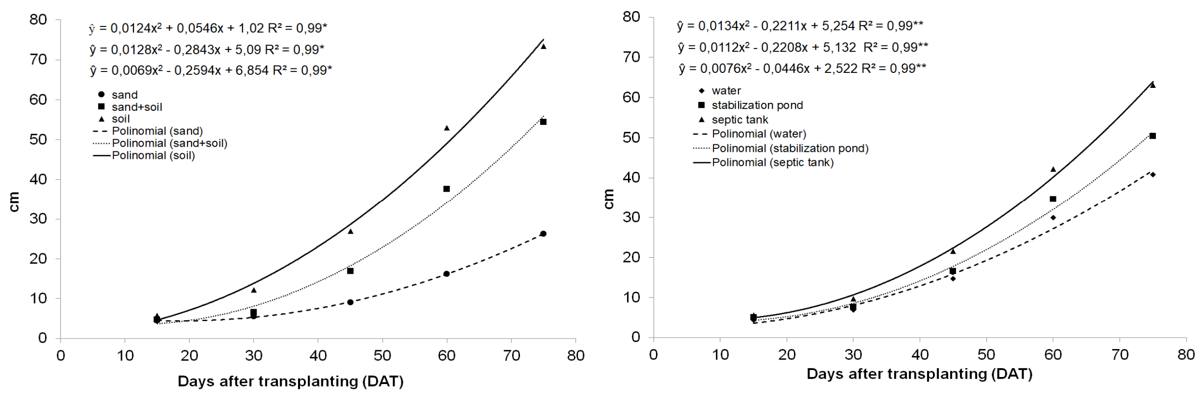


Figure 5. Assessment of cherry tomato plant growth as a function of filtering medium and irrigation effluent

treatment, it presented 22.3 cm of variation in growth compared to the default (water) and 12.8 cm compared to the stabilization pond, standing out as the most appropriate type of irrigation in terms of development of the cultures. Cunha et al. (2016), evaluated the influence of using treated sewage effluent enriched with commercial nutrients and conventional nutrient solution with different types of substrates on Sweet Grape tomatoes. Based on this study, they found that when the treated sewage was associated with a substrate formed by washed sand and coconut fiber, it caused the highest length average value in fruits classified as small, reaching a length of 2.52 cm, while when associated with this substrate to the treatment with nutrient solution, the height reached 2.23 cm. These values were low when compared to the averages found here, reaching average heights of 60 cm when using post septic tank effluent. Among the domestic effluents used, tomatoes irrigated with effluents post septic tank developed more than the ones irrigated with effluent from the stabilization pond. Factor justified by the presence of more nutrients and organic matter at the outcome of the septic tank. Based on the data presented in Tables 2 and 3, the amount of nitrogen present in the effluents post septic tank is 16% more than the stabilization pond, for Phosphorus and COD, the values are 29.8% and 33.5% respectively. Based on the data, it was possible to evaluate a significant variation between the filtering medium used from 45 days after planting. The fertilized soil served as a default (witness) for the growth of tomatoes as it is the method normally used for planting. Relating to the sand filtering medium, the soil presented 41.6 cm more in the average growth variation at 75 days after planting, while in relation to the sand plus soil substrate, the variation was 16.3 cm. Between the substrate sand plus soil and sand, the variation was 25.3 cm in growth. The soil used has more nutrients than sand, being 96% more Phosphorus, 92% Potassium, 98% Calcium, and 93% Magnesium. Thus, the tomatoes that developed in contact with the cultivation soil, obtained greater growth. On the other hand, it was found that although the soil provides a higher growth, the tomatoes planted in the sand filter medium also show growth. During the experiment, before the maturation stage, two cherry tomato plants showed signs of disease, these were in the soil and the VF-CW-ST (S+S) plastic containers. The disease was identified as bacterial wilt. According to Lopes (2009), bacterial wilt is one of the main diseases of Solanaceae in tropical and subtropical countries. Being the most important disease of tomato in Brazil's North Region. The most typical symptom is the wilting of the plant from top to bottom, resulting from the partial or total interruption of the flow of water from the roots to the top of the plant. The bacterium (*Ralstonia solanacearum*) lodges in the water-carrying vessels (xylem) and can remain in the soil for many years, thus making it impossible to grow Solanaceae in infested land for a long time.

The favorable conditions for the development of the disease are susceptible cultivars and hot and humid environments, occurring with greater intensity during rainy summer days. In irrigated crops, leaky pipes and drippers provide excessive soil wetting, where foci of wilted plants appear. Plantings conducted at low temperatures can escape the disease, even with the bacteria present in the soil. The control of bacterial wilt, after its manifestation in the field, is very difficult. Thus, monitoring is necessary for units of constructed wetlands that use crops susceptible to the disease. According to Lopes (2009), the bacterium multiplies faster at high temperatures, and winter crops are less prone to the occurrence of the disease. Another form of prevention is to avoid using places where the disease has occurred, as the pathogen survives for years in the soil, which becomes a problem not only for constructed wetland units. Clay sites, subject to waterlogging, should also be avoided, in which case CW units with soil become more prone. Solarization for two to three months, although it does not eliminate the bacteria, significantly reduces its population in the soil, and should be considered in regions subject to a high incidence of sunlight for several consecutive days. However, by only reducing the population of the pathogen in the soil, other complementary measures are necessary to obtain a good level of control. Also, according to the author, for cultivation in crops, it is recommended that they are pulled out carefully, placed in large plastic bags (garbage bags), and removed, avoiding spreading contaminated soil to other plants. Diseased plants should be burned or buried in a deep pit after being covered with a thin layer of lime. A layer of lime can also be placed at the site of the uprooted plant to avoid contaminating neighboring plants with infested soil.

CONCLUSION

In summary, the study demonstrates that the effluent post septic tank allows for a greater supply of nutrients and organic matter that significantly influences plant growth. The systems without soil, only sand, present a significant removal, for the parameters P and turbidity, that is, better performance in the treatment of pollutants. It is also worth mentioning that tomatoes irrigated with water showed lower growth than those with treated effluent (post septic tank and stabilization pond), being a viable option to avoid the use of mineral fertilizer and contributing to the fixation of carbon and nutrients in the soil and the production of biomass and food. The VF-CW-ST, with post septic tank effluent and only sand, which presented the best performance in pollutant removal, obtained removals of 70, 59, 77, 89, 98, 43, 84, and 91%, for the parameters BOD, COD, P, TN, NH4, $NO2^-$, $NO3^-$, and turbidity, respectively. For pathogen removal, both VF-CW-ST and VF-CW-SP, with soil or without soil, showed removal of 2 logarithmic places for TC and *E.coli.* Although the filtering medium with soil impaired the performance of the VF-CW-ST and VF-CW-SP in removing pollutants, it allowed the greater growth of the tomato (*Solanum lycopersicum var. Cerasiforme*) and proved to be efficient in the nitrification process and similar in pathogens removal. Although it is more susceptible to bacterial wilt, which can lead to lower productivity. The VF-CW with soil plus sand reached the end of 75 days after transplanting with a height of 55 cm, while the VF-CW with only sand did not exceed 25 cm. On the other hand, the VF-CW that received effluents post septic tank reached 64 cm, while the post stabilization pond reached 50 cm, showing the positive and significant impact of the treated effluent. It is recommended that studies to evaluate business models with reuse of treated effluents for agricultural productivity with solutions based on nature and conventional WWTPs, take into account the results obtained and that were significant, such as removal of pollutants, plant growth, type of effluent, organic matter loading and nutrients and also the type of CW filtering medium and the plants filtering medium.

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