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PERFORMANCE OF CONSTRUCTED WETLAND SYSTEM USING DIFFERENT SPECIES OF MACROPHYTES IN THE TREATMENT OF DOMESTIC SEWAGE TREATMENT

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Wastewater
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Typha ssp.
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ABSTRACT

The objective is to assess the initial performance of a constructed wetland system and the development of the macrophyte species cattail(*Typha* spp.) (CWt), piripiri (*Cyperus giganteus*) (CWp), and white garland lily (*Hedychium coronarium* Koehne) (CWl) and an suncultivated (UNc) on the treatment of sewage from toilets and from a restaurant. Changes in hydrogen potential, electrical conductivity, total suspended solids, total solids, biochemical oxygen demand, chemical oxygen demand, turbidity, nitrate, ammonium nitrogen, total phosphate, hydraulic retention time (HRT), and potential evapotranspiration (PET) and the development and adaptation of macrophytes were measured. The surface area of each constructed wetland (CW) had a surface area of 16.25 m^2 and average volume treated of 0.40 m^3 d^{-1}, with continuous variable horizontal subsurface flow equally fed with sewage previously treated in three septic tanks in series, with an individual useful volume of 5.100 L. The PET in CWt, CWp and CWl was higher than that of UNc. The highest pH values were obtained in the effluent of CWp, CWt, and CWl. The use of macrophytes did not influence the EC, TS, $BOD_{5,20}$, COD, and nitrate were lower and ammonium nitrogen and total phosphate were higher in the effluent of CWs and UNc in relation to the influent. The efficiency indexes that showed a very strong Pearson correlations (> 90%) were pH correlated with $N\text{-}NH_4^+$, turbidity correlated with COD, TS correlated with EC, and $BOD_{5,20}$ and COD correlated with NO_3^-.Piripiri and cattails showed the best development of plants in the second half of CW.

Palavras-chave:
Aguas residuárias
Evapotranspiração
Wetlands horizontal
Typha ssp.
Cyperus giganteus
Correlação de Pearson

DESEMPENHO DE LEITOS CULTIVADOS UTILIZANDO DIFERENTES ESPÉCIES DE MACRÓFITAS NO TRATAMENTO DE ESGOTO DOMÉSTICO

RESUMO

Objetivou-se avaliar a adaptação inicial de um sistema de leitos cultivados (LC) e o desenvolvimento das espécies de macrófitas taboa (*Typha* spp) (LCt), papiro-brasileiro (*Cyperus giganteus*) (LCp) e lírio do brejo (*Hedychium coronarium Koehne*) (LCb) e um leito não cultivado (LNc), no tratamento de esgoto de sanitários e de um restaurante. Foram medidas as mudanças no potencial de hidrogênio, condutividade elétrica, sólidos suspensos totais, sólidos totais, demanda bioquímica de oxigênio, demanda química de oxigênio, turbidez, nitrato, nitrogênio amoniacal, fosfato total, tempo de retenção hidráulica (TRH) e evapotranspiração potencial (PET) e o desenvolvimento e adaptação de macrófitas. A área superficial de cada LC foi de 16,25 m^2 e o volume médio tratado foi de 0,40 m^3 d^{-1}, com fluxo subsuperficial horizontal variável contínuo alimentado igualmente com esgoto previamente tratado em três tanques sépticos em série, com volume útil individual de 5,100 L. O PET em LCt, LCp e LCl foi maior que o de UNc. Os maiores valores de pH foram obtidos nos efluentes de LCp, LCt e LCl. O uso de macrófitas não influenciou na CE, TS, $DBO_{5,20}$, DQO e o nitrato foi menor e nitrogênio amoniacal e fosfato total foram maiores no efluente de LCs e UNc em relação ao afluente. Os índices de eficiência que apresentaram correlações de Pearson muito fortes (> 90%) foram o pH correlacionado com $N\text{-}NH_4^+$, a turbidez correlacionada com DQO, TS correlacionado com CE e $DBO_{5,20}$ e DQO correlacionado com NO_3^-. Papiro e taboa apresentaram melhor desenvolvimento das plantas na segunda metade dos LC.

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INTRODUCTION

The treatment of sewage by conventional systems currently requires high investment, operation, and maintenance costs. As a result, in many cases, effluents are discharged into untreated natural watercourses and pollute rivers and the groundwater, causing an increased risk of waterborne diseases (SOLER *et al*., 2019).

To treat sewage, especially in small and medium volumes, the use of septic tanks (ST) followed by constructed wetlands (CW) is a promising alternative that has been used in various locations and geographical conditions in several countries. 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. Wastewater containing organic materials and ammonium nitrogen can cause serious ecological problems if discharged into water bodies (ZHENG *et al*., 2019). Ammonia is toxic to many aquatic plants and animals (LIU; VON WIREN, 2017).

For Zhao *et al*. (2018), in general, CWs are good for the removal of suspended and organic solids in terms of $BOD_{5'20}$ and COD, but inconsistent, and often bad for reducing nutrients such as N and P. Unless the dimensioning is performed aiming to remove N and P, the efficiency may be high and able to soften the effects of eutrophication in watercourses. However, their low total nitrogen (TN) removal efficiency remains a pressing issue (MA *et al.,* 2019). A remoção em CWs de alguns atributos do efluente nem sempre é suficiente para atingir os padrões de lançamento, mesmo assim a eficiência destes sistemas de tratamento de esgoto é superior a de muitos reatores convencionais. The removal in CWs of some attributes of the effluent is not always sufficient to reach discharge standards, yet the efficiency of these sewage treatment systems is higher to that of many conventional reactors. At the same time, CWs are ecological systems that remove suspended solids, eutrophic organic attributes, pathogenic microorganisms, and toxic metals (SOLER *et al*., 2019, NIVALA *et al*., 2019). Therefore, a careful removal of contaminants is an urgent challenge that needs to be considered in sewage treatment.

According to Wang *et al*. (2017), there is a growing demand for alternative technologies to treat polluted water and wastewater that require minimal economic resources to both implement and operate a treatment system. In this sense, CWs represent a sustainable option. They have been used for decades to treat wastewater.

CWs have greater advantages compared to conventional treatments. They improve ecological biodiversity, are aesthetically integrated into the landscape, and can be an alternative source of income due to the possibility of manufacturing utensils using macrophyte fibers. Their implantation and maintenance are simple and consume little to no energy.

Among the main components of wetland systems, cultivated macrophytes stand out for favoring the entry of oxygen into the effluent mass, allowing the formation of a dense layer of biofilm with a large amount of microorganisms in roots, acting as a filter medium, and absorbing salts present in the effluent, thus reducing eutrophication when released into surface and groundwater sources. However, these functions are greatly affected by macrophyte species, as they present differences in density and deepening of the root system, in the absorption capacity of salts, and in the formation of biomass in shoots.

In addition, Chen *et al*. (2016) reported that plants release exudates from roots, affecting the density and diversity of root microbiota and increasing the rates of nutrient removal from the effluent. Thus, in the treatment of sewage with CW, the efficiency of pollutant removal varies considerably depending on a complex combination between physical, chemical, and biological factors to remove contaminants (ZHANG *et al*., 2014).

Nivala *et al*. (2019) evaluated 15 pilot-scale subsurface flow constructed wetlands with different designs, all fed with the same primary treated domestic sewage, and observed that intensified designs are capable of achieving high quality effluents that are able to comply with increasingly stringent discharge and re-use standards. Monitoring planted and unplanted systems over the long-term will give deeper insights into the long term influence of mature plant growth on the role of plants in wetland treatment systems and the overall treatment efficacy of constructed wetland systems.

They also reported that the physiological and productive characteristics of plant species are factors that influence the operational conditions and the efficiency of this treatment system regarding pollutant removal. Therefore, it is important to evaluate reactor performance and the influence of plant species with a deep, fasciculate growth of roots. For Silva *et al*. (2020), plant characteristics such as local climate adaptability, photosynthetic rate, oxygen transport capacity, pollutant absorption capacity, resistance to pests and diseases, and root system development should be considered.

The choice of the macrophyte for the CW is related to tolerance regarding environments saturated with water, growth potential, chemical composition of sewage, presence of these species naturally in the region where the project is implemented, cost for planting and maintenance, need for regular pruning, and use as raw material for making utensils or even for landscaping or decorative purposes (IWA, 2000). Among the species available at the study site for implantation in constructed wetlands that have potential for landscape purposes, there are the cattail, piripiri, and white garland-lily, which also serve as raw material for the manufacturing of several items, such as purses, bags, etc.

This study aimed to determine the influence of the changes in physical and chemical attributes in the influent and effluent, hydraulic retention time, and potential evapotranspiration of a sewage treatment system composed of three septic tanks in series, followed by CW of horizontal subsurface flow with a variable continuous flow cultivated with the macrophyte species cattail, piripiri, white garland lily, and an uncultivated bed (UNc).

MATERIALS AND METHODS

The experiment was carried out at the Fazenda Água Limpa (FAL), which belongs to the University of Brasília (UnB), located at 15º56'-15º59' S and 47º55'-47º58' W, altitude of 1,100 m. According to the Köppen classification, the climate is Aw, characterized by two well-defined seasons: a hot and rainy from October to April and a cold and dry season from May to September (ALVARES, 2014).

The climate information was obtained from an agro-meteorological station located 300 m from the sewage treatment station (STS). The average temperatures varied between 20.8 and 25.3 °C, the maximum temperature varied between 28.2 and 35.1 °C,and the minimum temperature varied between 9.2 and 17.9 °C. Solar incidence varied between 8.3 and 22.1 MJ m^{-2}. The rainfalls were 2.2 mm on 11/5, 18.4 mm on December 12, 2015, and 3.8 mm on December 7, 2015, this being the last day of collection of affluent and effluent for analysis.

Sewageis generated in toilets and in the FAL restaurant and, being the sewage treatment station (STS) composed of three septic tanks (ST) in series comprising polyvinyl chloride (PVC) reservoirs with an individual useful volume of 5.100 L followed by a passage box (PB) with a total capacity of 72 L, from where sewage is distributed equally to three units of constructed wetlands (CW) and a UNc (control) of horizontal subsurface flow with continuous and variable flow (Table 1). At the PB, four not drowned triangular spillways with an internal angle of 38º were installed, from where four PVC pipes of 40 mm in diameter come out, one for each CW and UNc.

The STS began operating on July 18, 2015, but the macrophyte species cattail (*Typha* spp) (CWt), piripiri (*Cyperus giganteus*) (CWp) and white

Table 1. Dimensions and characteristics of CW and UNc and gravel used as support

Fiberglass structures (m)				
Total high	Long	Wide	Wall thickness	Internal effluent height
0.50	6.50	2.50	0.0003	0.47
Gravel				Gravel not wet by the effluent to avoid exposition of water on the surface (m)
#	Porosity (%)	Total volume for each CW(m^3)	Useful volume (m^3)	
2	48	8.12	3.82	0.03

garland lily (*Hedychium coronarium Koehne*) (CWl) were transplanted on August 18, 2015 (102 seedlings by CW), spaced 0.42 m by 0.37 m (Figure 1), resulting in 12 plants m^{-2} and an uncultivated system (UNc), assessed as for adaptation and development with measurements of the entire plant development taken at 60, 80, 120, and 180 days after transplantation (DAT) using a measuring tape with 1 mm precision. The macrophytes at 180 DAT did not show complete distribution over the constructed wetlands and there were new plants emerging, which is why they were not pruned.

Each constructed wetland was divided into four blocks measuring 2.5 x 1.6 m to measure the development of macrophytes as a function of location in relation to the inlet and outlet sewage. The accumulation of solids in the gravel layer was carried out by opening trenches at the entrance and exit of the sewage system. No measurements were taken, and according to visual observation only, the gravel was practically free of solids between the pores at the 0.20 m deep layer.

The raw sewage (RS), the influent and the effluent to CW and UNc were collected at 9:00 am, 11:00 am, and 1:00 pm to form a composite sample, separately for each point evaluated (type of effluent).The sample was stored it in plastic bottles with a 1.0 L capacity and preserved them in a polystyrene box with ice. The collections of influent and effluent were performed on August 20 (2 DAT), September 8 (21 DAT), September 21 (33 DAT), October 6(48 DAT), October 21 (63 DAT), November 5 (78 DAT), November 20 (93 DAT),and December 7, 2015 (110 DAT). On these dates, the volume of influent and effluent to CW and UNc was quantified by the direct volumetric method using a bucket with a capacity of 10 L, precision of 0.1 L. The volume of influent released in the respective CW and UNc was collected for 9:00 hours (8:00 am to 5:00 pm) (Table 1) because the flow was practically zero outside this time frame.

Equation 1 calculates the hydraulic retention time (HRT), as Metcalf & Eddy (2003) proposed, which, due to the intermittent supply of the CWs, was applied for the period in which sewage was supplied. The HRT was obtained considering the effluent flow, however, the average of the influent and effluent flow can also be used, but not only the influent flow because it would have the disadvantage of not considering the water losses in the calculation.

$$\mathrm{HRT} = \frac{L\,W\,p\,h}{Q} \tag{1}$$

Where:
HRT = hydraulic retention time (days);
L = CWlength (m);
W = CWwidth (m);
Q = effluent flow rate (m^3 d^{-1});
p = porosity of the support medium (decimal); and
h = depth of the effluent blade in CW (m).

To determine the potential evapotranspiration (PET), we calculated influentand effluent flows. The difference between them, in liters, was divided by tank surface area (m^2), thus representing PE in mm. The flow measurement dates were the same as those of sample collection for physical, chemical, and microbiological analysis.

Hydrogen potential (pH), electrical conductivity (EC), total suspended solids (TSS), total solids (TS), sedimentable solids (SS), biochemical oxygen demand ($BOD_{5,20}$), chemical oxygen demand (COD), nitrate ($N\text{-}NO_{3-}$), total phosphate (PO_4^{3-}), ammonium nitrogen ($N\text{-}NH_4^{+}$), and turbidity were analyzed according to the methodologies of the APHA (2012).

Figure 1. Transplantion of the macrophyte species cattail (*Typha* spp.) (CWt), piripiri (*Cyperus giganteus*) (CWp), and white garland-lily (*Hedychium coronarium* Koehne) (CWl) in the constructed wetlands

Equation 2 calculates the efficiency in removing physical and chemical attributes in ST and Equation 3 calculates it for CW and UNc as a function of the difference in flow between the influent and effluent due to potential evapotranspiration (ETP) (ALMEIDA; UCKER, 2011).

$$\text{Ef } (\%) = \frac{\text{Ca} - \text{Ce}}{\text{Ca}} x100 \tag{2}$$

$$\text{Ef } (\%) = \frac{(\text{Ca x Qa}) - (\text{Ce x Qe})}{(\text{Ca x Qa})} \text{x}100 \tag{3}$$

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

The averages were submitted to analysis of variance by F test at p = 0.05. When significant, the Duncan probability test was applied at p = 0.05 using the software XLSTAT (ADDINSOFT, 2015). When there was a significant interaction between factors, an unfold was performed considering the eight dates of analysis as replications.

RESULTS AND DISCUSSION

Hydraulic retention time (HRT) and potential evapotranspiration (PET)

The mean HRT were 9.2 days (CWt), 9.0 days (CWp), 8.4 days (CWl), and 8.8 days (UNc) considering 24 h (Table 2), while the mean HRT in the septic tanks was of 9.0 days. However, if only the sewage flow period is considered, that is, from 8:00 am to 5:00 pm, the HRT decreases to about 3.3 days on average. The rest period of the effluent in the support medium of approximately 15 hours (5:00 pm to 8:00 am) possibly interfered with the removal of total nitrogen (TN), total phosphorus, and COD, among others. Thus, both rest and intermittent application influence the efficiency of the CW. According to Silva *et al*. (2020), intermittent aeration allows the simultaneous occurrence of nitrification and denitrification processes, improving the removal of TN in horizontal subsurface-flow constructed wetlands. In addition, the use of intermittent aeration also improves the performance of constructed wetlands in removing COD and total phosphorus. Thus, the HRT influences the efficiency of the CW, as observed by Md Sa'at *et al*. (2019) in horizontal subsurface flow CWs filled with sand and vegetated with *Cyperus alternifolius*, considering the HRTs of 3, 6, and 12 days, observing the best removal efficiency of TP and SS in the 6-day HRT, reaching the removal of 71% and 93%, respectively, for COD and ammonia nitrogen, and observing the best treatment performance in the 12-day HRT, reaching93% and 95%, respectively. The lower values of HRT in the CWl and UNc are due to the lower PET in relation to CWt and CWp because the white garland lily had less coverage of bed surface, affecting mainly up to half the bed length, possibly because of use of sanitizers to clean the restaurant, where plants showed less development and 80% of plants died at half the length.

The macrophytes cattail and piripiri best adapted to the sewage composition, providing a greater development and therefore a greater PET. The values were 3.0 mm $d^{-1}$for CWp, 2.5 mm $d^{-1}$for CWt, 2.3 mm d^{-1} for CWl, and 1.4 mm d^{-1} for UNc, representing a difference of volume of E in relation to I of 72.5, 114.1 and 64.8% of CWt, CWp and CWl, respectively (Table 2).These values are well below those Sérvulo *et al*. (2019) obtained, whereobserved a higher PET for CWt (10.0 mm d^{-1}), followed by CWp (9.4 mm d^{-1}) due to climatic conditions of the research period, since that research was carried out in the same constructed wetlands analyzed in this study. Brasil and Silva (2008) observed inCW with cattail (*Typha* sp.) with a constant application rate of 60, 47, 23, and 35 L m^{-2} $d^{-1}$for over six months and reported an average potential evapotranspiration of 9.3 mm d^{-1} estimated by the Penman-Monteith equation. This value is higher than that obtained in this work due to factors such as plant density in the constructed wetlands and evapotranspirometric demand of the site. The present study involved the evaluation of the CWs from the transplantation of the macrophytes until the next moment of cutting them. Thus, there was a period in which plant density was low and, therefore, the results of removal efficiency of physical and chemical attributes would be different from those obtained if the evaluation had been carried out from the beginning with the CWs completely covered by macrophytes.

Development of macrophytes

At 50 DAT,there was replacement of six seedling of cattail, 30 seedlings of piripiri and 32 seedlings of white garland lily. At 95 DAT, 13 seedlings of piripiri were replaced. Plant death occurred mainly in block 1, especially among cattails and white garland lilies, which also showed less development due to the sanitizer used for restaurantasepsis, which are specific for eliminating *E. coli,* as well as detergents, which poisoned plants (Figure 2). Although the evaluation of these substances in the effluent has not been carried out, the electrical conductivity of the effluent, which can be a stress factor for the plant, presented lower values compared to those obtained by other authors (NIVALA *et al*., 2019; SOLER *et al*., 2019; CHEN *et al*., 2016; COLARES; SANDRI, 2016). These authors did not verify plant death as in this study, obtaining other good conditions favorable to the development of macrophytes. Thus, there is the hypothesis of intoxication caused by excess of the sanitizer used for restaurant asepsis.

In the first 90 DAT, the development was very slow. However, from this period onwards, with the deepening of the root system and especially with the onset of more intense rainfallsin October, besides the rise in temperature from the month of August onwards, the development of the three species of macrophytes accelerated, but always with a great difference in growth between blocks. This effect is more evident for cattails and white garland lilies (Figures 2 and 3).

For piripiri,on the other hand, the difference in plant development was not so evident, showing a better adaptation to the type and composition of the sewage in all blocks(Figure 2), possibly as piripiri was is more tolerant to the intoxication caused by the excess f the disinfectant used for restaurant asepsis. The cattail plants in block 1 showed yellowing (Figure 2) possibly due to poisoning,

Table 2. Average daily volume of influent (I) and effluent (E) and difference (Dif), in percentage, of volume of E in relation to I of CW and UNc

CWt			CWp			CWl			UNc		
I	E	Diff.	I	E	Diff.	I	E	Diff.	I	E	Diff.
m^3d^{-1}		(%)	m^3d^{-1}		(%)	m^3d^{-1}		(%)	m^3d^{-1}		(%)
0.403	0.288	39.90	0.401	0.269	49.50	0.408	0.296	38.00	0.400	0.325	23.10
Hydraulic retention time (days)											
9.20			9.00			8.40			8.30		
Potential evapotranspiration (mm d^{-1}) and (% in relation to UNc)											
2.40 (72.50)			3.00 (114.10)			2.30 (64.80)			1.40		

Cattail (CWt), piripiri (CWp), white garland lily (CWl), and uncultivated bed (UNc)

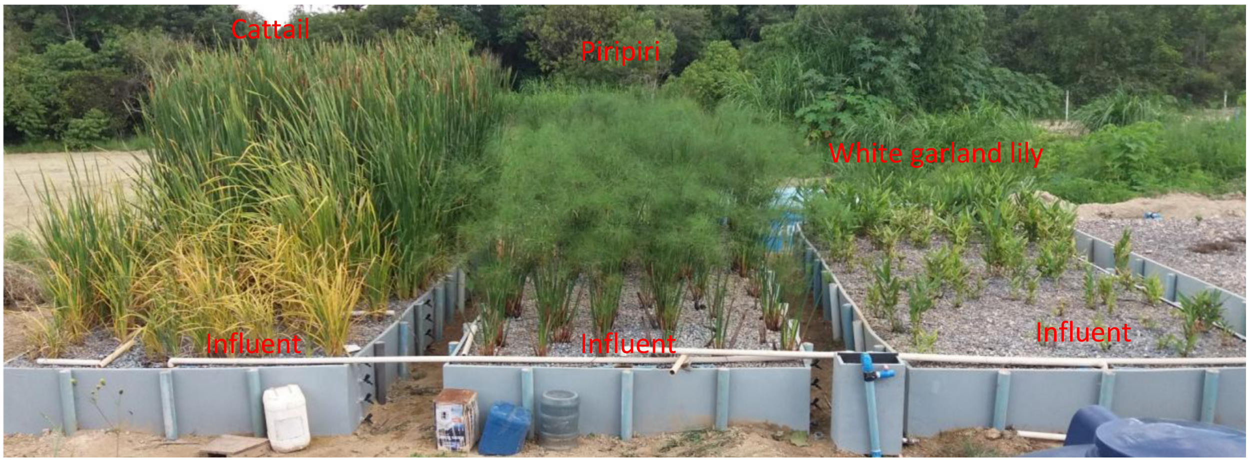

Figure 2. Constructed wetlands with species of macrophytes at 161 DAT

since in December 2015 and January 2016 a low amount of sewage was generated because there were no classes at Fazenda Água Limpa, causing less dilution of sanitizers and, therefore, a greater concentration of them in the sewer.

No pruning or removal of dead leaves was performed because the constructed wetlands had been in operation for about six months, so that the plants were in full development, not yet showing signs of ripening, and the beds were not yet fully populated by plants. The growth of cattails up to 90 DAT was slow, with a better performance in block 4.

The height of cattail plants varied between measurement dates from 42.3 cm at 79 DAT to 93.95 cm 161 DAT, as well as between blocks: in block 1, it was 94.0 cm; in block 4, it was 216.7 cm at 161 DAT (Figure 3). The greatest growth variation among cattail plants occurred in block 3, with a variation of 144.3 cm between 80 and 161 DAT. In December 2015 and January 2016, there was a continued growth in all blocks of cattails and piripiris, although not the same and more expressive in block 4. The development of piripiri was marked between 64 and 161 DAT, with the greatest growth variation occurring in block 4, whose plants presented 70.1 cm in height between these dates (Figure 3).

The greatest variation in height of the white garland lily occurred in block 4, which increased 22.1 cm (Figure 3) between 65 and 161 DAT. In block 1 (wetland entry), where it is possible to observe a decrease in its growth due to the death of plants in a very marked way (Figure 3), the species adapted the worst. At 161 DAT, about 80% of the plants in blocks 1 and 2 died (Figure 2 and 3).

The number of plants of the macrophyte species Typha and white garland lily in block 1 was lower than the others, with the exception of 161 DAT for the former species, and more accentuated in the second species (Figure 4) due to the death of many plants because they were less tolerant to sanitizers present in the sewer. As for piripiri, the highest number of plants was observed in block 2, and at all DATs of this species and white garland lily, there was greater amplitude (difference between the highest and lowest number of plants) in all blocks. This did not occur with cattails. At 161 DAT, the number of plants in block 4 was 500 plants, while in block 2 it was only 182 plants (Figure 4).

The species of macrophytes used in CW systems does not always interfere with the removal of all pollutants from the sewage, as it depends on its adaptation to the composition of the sewage, as well as on the type of support material, HRT, and its distribution on the surface, as demonstrated by Fia *et al.* (2017) when evaluating CWs using the cattail and Tifton 85 grass. They observed that the removal of BOD and SST did not present differences, as the efficiency of COD removal was higher with cattail. On the other hand, except for Mg, the macrophytes did not influence the removal of macro or micronutrients.

The coefficient of variation (CV) of the number

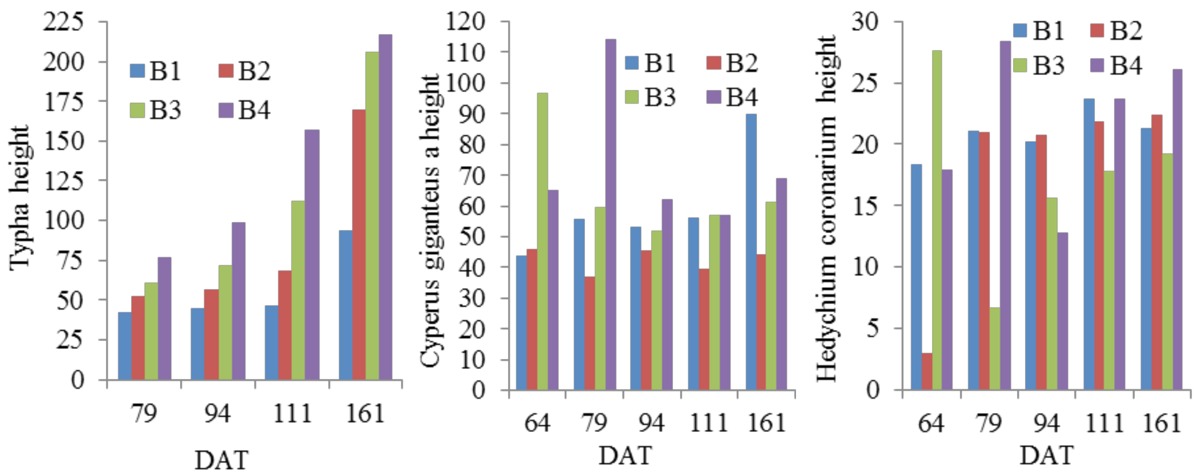

Figure 3. Average height (cm) of the macrophyte species cattail *(Typha* spp, piripiri (*Cyperus giganteus*) and white garland lily (*Hedychium coronarium* Koehne) in four blocks measuring 2.5 x 1.6 m in each constructed wetlandand different days after transplantation (DAT)

of plants between the blocks decreased over time from 65% at 64 DAT to 14% at 161 DAT and from 80% at 64 DAT to 49% at 161 DAT for cattails and piripiri, respectively. This did not occur for white garland lily, for which the lowest CV was at 94 DAT (55%) and at 161 DAT (54%) due to the large number of dead plants in blocks 1, 2, and 3 (Figure 4).

Physical and chemical attributes of raw sewage (RS), influent and effluent of cultivated beds (CW)

The EC,in absolute values, was lower in raw sewage (RS) (619.92 µS cm^{-1}). However, after passing through the three STs, there was an increase to 904.33 µS cm^{-1}, similar as the value observed after CWt, CWp, CWl and UNc, i.e., 908.8, 956.1, 975.2, and 965.9 µS cm^{-1}, respectively (Figure 5). The vast majority of plants in the CWl died and, combined with the more superficial root system, as observed in loco, the salts that could influence the EC were not removed, which is why the UNc presented a slightly higher value, probably due to the variability of the environment in the CWl and UNc. Although not significant but demonstrating that CWt was mre efficient in absorbing nutrients from the effluent compared to CWp and CWl,these values are slightly higher than the those of the influent. This may be related to the formation of ions in the effluent due to mineralization of organic matter, which releases more salts than macrophyte plants can absorb, and the plant does not absorb everything that is ionized in the medium. At the same time, the root system concentrated on the 0.24-m surface layer of three CWs.

Thus, the effluent that moved in the 0.23 m deep layer of the substrate was not affected by the absorption of salts by the root system of plants. Thus, to obtain a greater absorption of salts using CWt, CWp and CWl in substrate with gravel #2, the depth of the substrate layer must be shallower than that used here, which was proved by the trenches opened at different points of the CWs. However, this would imply in a reduction in the useful life, a behavior that should be better investigated for each species of macrophyte and type of support medium, as proved by Yang *et al.* (2018). who observed a gradual accumulation of the total suspended solids from the influent within substrates, with a concentration of solids accumulated within the system following 180 days of operation of 4.68 g, (2.38 kgm^{-2}) and an accumulation rate of 4.76 kg m^{-2} $year^{-1}$). Adverve correlation between the concentration of accumulated solids and operation time was confirmed with a Pearson correlation coefficient of 0.94, that is, a linear fitting was also conducted and the data matched well, with a R^2 of 0.871, showing that solids accumulated at a uniform speed over time at a rate of $5E^{-5}$ gg^{-1} gravel per day.

However, it would greatly reduce the capacity of the substrate to act as a filter medium, since observed that most retained solids were located at the deeper layer (0.20 m), which would in turn cause clogging of pores of the support medium and,

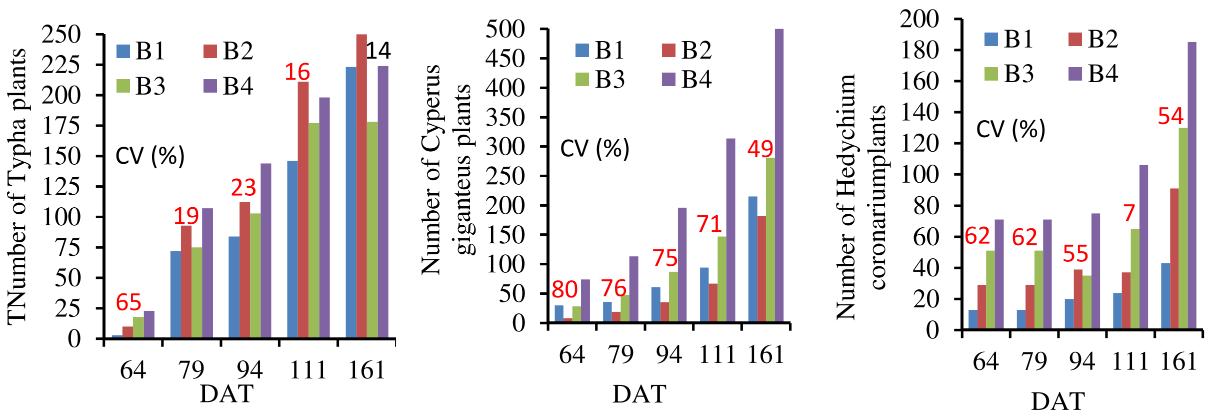

Figure 4. Number of cattails *(Typha* spp), piripiris (*Cyperus giganteus*) and white garland lilies (*Hedychium coronarium* Koehne) in four blocks measuring 2.5 x 1.6 m in each constructed wetlandand different days after transplantation (DAT)

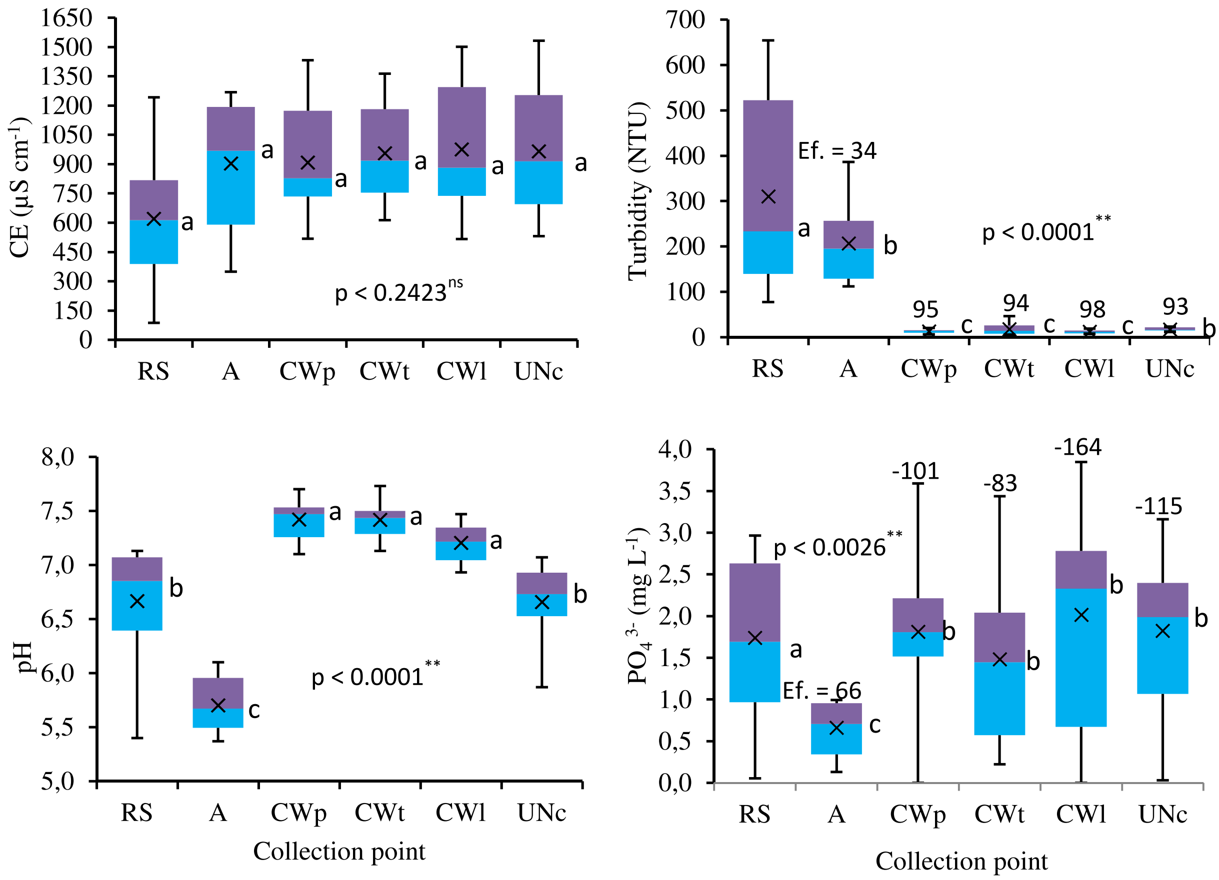

Figure 5. Box-plot of mean values of electrical conductivity (EC), hydrogen potential (pH), Turbidity, total phosphate, DP, CV, and Ef, and test of comparison of means between the points evaluated in the sewage treatment plant. Where:RS: raw sewage, A:influent to CW; CWt: bed effluent grown with cattail; CWp: bed effluent grown with piripiri; CWl: bed effluent grown with white garland lily; UNc: effluent from uncultivated bed. Ef: efficiency between influent and effluent in CWand UNc for turbidity and PO_4^{3-}; ns: not significant and ** significant by Duncan test at 5% probability

therefore, progressively reduce HRT. According to Knowles *et al.* (2011), clogging is a major operational and maintenance issue associated with the use of subsurface flow wetlands for wastewater treatment and can ultimately limit the lifetime of the system. The occurrence of clogging depends on the context of various design and operational parameters, such as wastewater characteristics, upstream treatment processes, intermittent or continuous operation, influent distribution, and media type.

The variation in relation to the average of EC in RS was higher than that of the other evaluated points. This is due to the great variation in the composition of the RS because the use of toilets is not constant in the restaurant of the FAL/UnB and generates larger volumes between 11:00 am and 1:00 pm resulting from utensils washing and between 4:00 pm and 4:40 pm from cleaning and sanitizing. This creates peak sewage flows. In the other evaluated points, the EC was more stable due to a small effect of equalization promoted by septic tanks and CWs. Even so, the variation in relation to the average of EC in the influent, was lower than that of the effluent of CW and UNc (Figure 5).

The pH in crude RS was 6.67. After the three ST, it decreased significantly to 5.40 (influent to CW, Table 3) due to the action of acid-forming bacteria, which fractionate the organic matter, producing volatile acids (VON SPERLING, 2016) and resulting in a reduction in medium acidity, a fact observed within the ST. However, when passing through CW and UNc, the pH increased to 7.42 in CWt and CWp, to 7.20 in CWl, and to 6.66

in UNc,the latter being significantly lower than that of CWs, but equal to the raw sewage. The increase in pH value in the effluent in relation to the influent occurred both in the CW and in the UNc due to the mineralization of organic material (FIA *et al.*, 2017) and the consequent release of Ca, Mg, K and Na ions, which undergoes a basic reaction, causing the pH to become more alkaline. Travaini-Lima and Sipaúba-Tavares (2012) observed a different behavior from this study, justifying that the CO_2 from the respiration of microorganisms in the constructed wetland might have helped in the decrease of pH in the outlet.

The average pH values were similar to those Colares and Sandri (2013) observed for the sewage influentand effluent of a university unit treated with three ST in series followed by three tanks of CW filled with natural gravel #2 and washed gravel grown with cattail.

Was observed that the influent and the effluent to the CW are suitable for release into class II water bodies, which must be between 5.0 and 9.0 (BRASIL, 2011). On the other hand, only the effluent in UNc showed a pH considered adequate to provide a greater availability of nutrients to plants, which is between 6.0 and 7.0. Therefore, recommend adjusting the pH of the CW effluent for direct use as irrigation, allowing greater absorption of nutrients by plants and reducing the possibility of obstruction of emitters in drip irrigation.

The average value of turbidity in RS was 310.25 NTU, decreasing to 206.88 NTU after the three ST in series, that is, a 33% decrease. The effluent from CWt, CWp, CWl and UNc, in relation to influent values, decreased by 95, 94, 96, and 93%, respectively (Figure 5). It was favored by the processes of filtration, sedimentation, assimilation by plants, and microbial metabolism of suspended residual matter and of colloidal matter in the CW and UNc substrate mass. The results of this study were different from those obtained by Sarmento *et al*. (2013), who noted that the control treatment, only containing gravel, provided the greatest removal (35.6%), followed by the treatments with *H. coronarium* (22.2%), *H. rostrata* (20.0%), and *Cyperus* sp. (−1.3%), which instead of reducing, increased turbidity. It is believed that an increase in turbidity, as well as the low turbidity removal of the other treatments is linked to the release of exudates and debris in the rhizosphere. According to Kadlec and Wallace (2009), the exudates released by roots, which help detoxify the rhizosphere, can influence the turbidity of the liquid medium.

The Ef for average decrease in turbidity between the RS and the influent to CW, and in this in relation to the effluent of CWp, CWt, CWl and UNc, were 34, 95, 94, 96, and 93%, respectively. This shows that STs were not efficient in removing particulate matter. This was possibly caused by sewage flow peaks, which keep part of the solids in suspension and then carry them to the CW (Figure 5), as shown by the high values of SD and CV in the ST. In CW and UNc, the values were lower.

Thus, an alternative to mitigate this effect is to use an equalization tank positioned before the ST. The reduction in turbidity in the CW and UNc effluent was similar. This demonstrates that macrophyte species do not influence turbidity. Crushed gravel is more effective in removing suspended and discharged solids and particulate matter from the influent, possibly because the flow of water occurs primarily below the layer with a higher root density.

In the RS, the mean value of PO_4^{3-} was 1.6 mg L^{-1} higher than that of the influent to CW (A) (0.8 mg L^{-1}, Figure 5). It can be attributed to the instability in the composition of the sewage from toilets and the restaurant. Due to the short time from the generation of sewage to the arrival at the STS there was no homogenization of sewage, that is, it consisted primarily of sewage from toilets and sometimes from sewage generated in toilets, an inherent behavior of small hydraulic circuits in the sewage network. Colares *et al*. (2020) verified, for example, relations between hydraulic retention time (HRT) and water depth in the CW with removal of P. At the same time, Dell'Osbel *et al*. (2020) reported that it is important to perform a second treatment after CW specifically to reduce the P content and avoid its release and pollution of water bodies, which will favor the management of water resources.

The contents of PO_4^{3-} inCWt, CWp, CWl and UNc did not present significant differences in relation to RS. At the same time, there was a significant reduction in ST with an Ef of 66%.

However, comparing the effluent to the affluent, there was an increase of 101, 83, 164, and 115, respectively, differing from the study by He *et al.* (2018), who showed that the removal efficiencies of the vertical flow constructed wetland (VFCW) and horizontal subsurface flow constructed wetland (HSFCW) were 63.7 and 53.7%, respectively, but being similar to the findings by Molle *et al*. (2005), who showed that VF CWs were generally not very efficient in phosphorus reduction.

The potential forms of phosphorus removal are plant absorption, biological processes, adsorption, and precipitation. For Dell'Osbel *et al.* (2020), the choice of the substrate is one of the main aspects in phosphorus removal, observing that high removal rates are obtained by applying materials of natural or artificial origins, as well as construction residues and industrial process byproducts. They further described that the absorption of phosphorous by plants is balanced by its release during tissue decomposition. Plants and microorganisms influence P availability and can also alter the pH, causing the precipitation of P with $CaCO_3$. Cheng *et al.* (2018) verified that at a the pH of 5, the reduction of P reached 71.5%, but if the pH was increased to values between 5 and 7, the adsorption capacity reached up to 0.5 mg of P g^{-1} substrate, and at a pH of 7, the removal efficiency increased to 95.6%. With pH values ranging between 7 and 11, phosphorous removal rates presented a slightly increase, reaching 99.4%.

Thus, the choice of materials for a substrate in CWs must have an affinity for phosphorus, possibility from recycling, low cost, and space availability, to meet the concepts of circular economy and sustainable development. Bolton *et al*. (2019) observed that hempite, melanterite, and dolomite-enriched gravel substrates treated with hematite, melanterite and dolomite before pyrolysis at 400°C were used for domestic wastewater treatment. They consistently reduced PO_4^- P concentrations in primary treated sewage to higher levels than those in wet control zones.

During the research, pruning the vegetation in beds was not carried out. If the vegetation used in cultivated beds is not harvested, it is considered a significant factor in the removal of phosphorus. The phosphorus returns to the aquatic system due to the natural decay of vegetation, which is a result of substrate saturation by P.

In RS, the mean TSS was 453.0 mg L^{-1}, which is higher than that Metcalf *et al*. (2003) reported, i.e., from 120 to 400 mg L^{-1}, with 66% PO_4^{3-} removal efficiency (Figure 5). In the influent to CW, the value was 235.6 mg L^{-1}, showing that septic tanks were efficient in the removal of TSS (Table 3). In the effluent of CWt, CWp, CWl and UNc, the values were 82.7, 80.57, 64.4, and 56.9 mg L^{-1}, respectively, with average removal efficiency of 64, 67, 72, and 72% for a HRT close to 9 days (Table 2). However, increasing this time would probably increase the removal of suspended solids. Sarmento *et al*. (2013) reported that in the secondary treatment of domestic sewage and in effluents with a higher polluting load, the removal efficiency is usually directly related to HRT. Brasil (2011) reported lower values, stating that the minimum removal Ef must be 20% for releasing waste into receiving bodies. The values were also higher than those obtained by Colares and Sandri (2013). The authors reported values in CW with crushed gravel #2, CW with washed gravel, and CW with natural gravel of 30, 43, and 54%, respectively, all grown with cattails. Ali *et al*. (2018) observed an overall maximum reduction of 89% in TSS, but they included the joint reduction of anaerobic reactors and CW. Thus, considering this criterion, the overall efficiency of the TSS was 76%.

TSS values show a great variability between replications (Table 3), mainly in RS, as it presents a great variation in RS composition (SD = 210.3 mg L^{-1}).Within a certain period, sewage from toilets and the restaurant (peak hours) predominates. The influent to CW and UNc also showed a high variability of TSS between collection dates (SD = 48.5 mg L^{-1}). This also occurred with the effluent

Table 3. Mean values of total suspended solids (TSS), total solids (TS), DP, CVand Ef, and test of comparison of means between the points evaluated in the sewage treatment plant

Variable	Collection point					
	RS	A	CWp	CWt	CWl	UNc
			TSS			
Mean (mg L^{-1})	302.40 a	164.60 b	82.70 c	80.60 c	64.40 c	56.90 c
SD (mg L^{-1})	144.70	48.50	147.40	124.00	110.00	50.30
CV (%)	47.90	29.40	178.20	153.90	170.80	88.50
Ef (%)		46	64	67	72	72
p			< 0.0001			
			TS			
Mean (mg L^{-1})	995.00 a	543.00 b	489.00 b	515.00 b	486.00 b	680.00 ab
SD (mg L^{-1})	311.00	190.00	271.00	249.00	258.00	340.00
CV (%)	31.30	35.00	55.00	48.00	53.00	50.00
Ef (%)		45	36	37	35	19
p			< 0.0317			

Where: SD: standard deviation; CV: coefficient of variation (%); RS: raw sewage, A:influent to CW; CWt: bed effluent grown with cattail; CWp: bed effluent grown with piripiri; CWl: bed effluent grown with white garland lily; UNc: effluent from uncultivated bed. Ef = efficiency between influent and effluent in CW and UNc: ns: not significant by Duncan test at 5% probability

of CWt, CWp, CWl, and UNc, with mean values of 147.4, 124.0, 110.0 and 50.3 mg L^{-1}, respectively, thus showing a direct relation with the quality and volume of sewage produced.

The TS also showed great variability: 995.0 mg L^{-1} in RS, within the range Von Sperling (2016) suggested, which is from 700.0 mg L^{-1} to 1,4 mg L^{-1}, and later reducing to 543 mg L^{-1} in A. For CWt, CWp and CWl, values were slightly lower than those of A, demonstrating that plants exerted little influence on TS removal possibly due to the retention of most sedimentary organic matter in the ST. The initial evaluations were carried out with macrophytes still in the beginning of tillering, while in UNc the values increased due to the release of particulate material and the occurrence of flow peaks. However, we observed that there was less variability in each site evaluated in the final replications, which corresponds to eight months after the beginning of the STS operation. The Ef removal of TS in the ST was 46%. Evaluating the application of ST in the treatment of domestic sewage, Colares and Sandri (2013) reported a reduction of 29% possibly due to the longer hydraulic retention time (HRT) in this experiment (close to nine days).

The CWt, CWp, CWl and UNc showed a TS removal of 36, 37, 35, and 19%, respectively (Table 3). The UNc did not present a significant value in the removal of TS in relation to CW, which may have been favored in part by the fact that there are no macrophytes in this bed and the filtration is small, since TS was distributed homogeneously within the mass of effluent from the beds.

The sedimentable solids (SS) values were 4.2 mg L^{-1} in RS and 0.1 mg L^{-1} in A, but were not observed in the effluent of CW and UNc.

The COD in RS was 1.2 mg L^{-1}, increasing to 1.3 mg L^{-1}at the exit of the ST (A), that is, an increase of 9% (Figure 6). It was because at the time of collection, the RS input coincided with few solids and, when passing through the STs, it transported suspended material due to hydraulic turbulence and especially peaks of sewage flow and particulate matter suspended in the effluent inside the STs, as Ali *et al*. (2018) observed. To reduce this effect in situations similar as those of this project, suggest collecting a larger volume of RS for a longer time aiming to better represent the composition of sewage, or carry out more frequent samplings, which reduces the impact of outliers on the average.

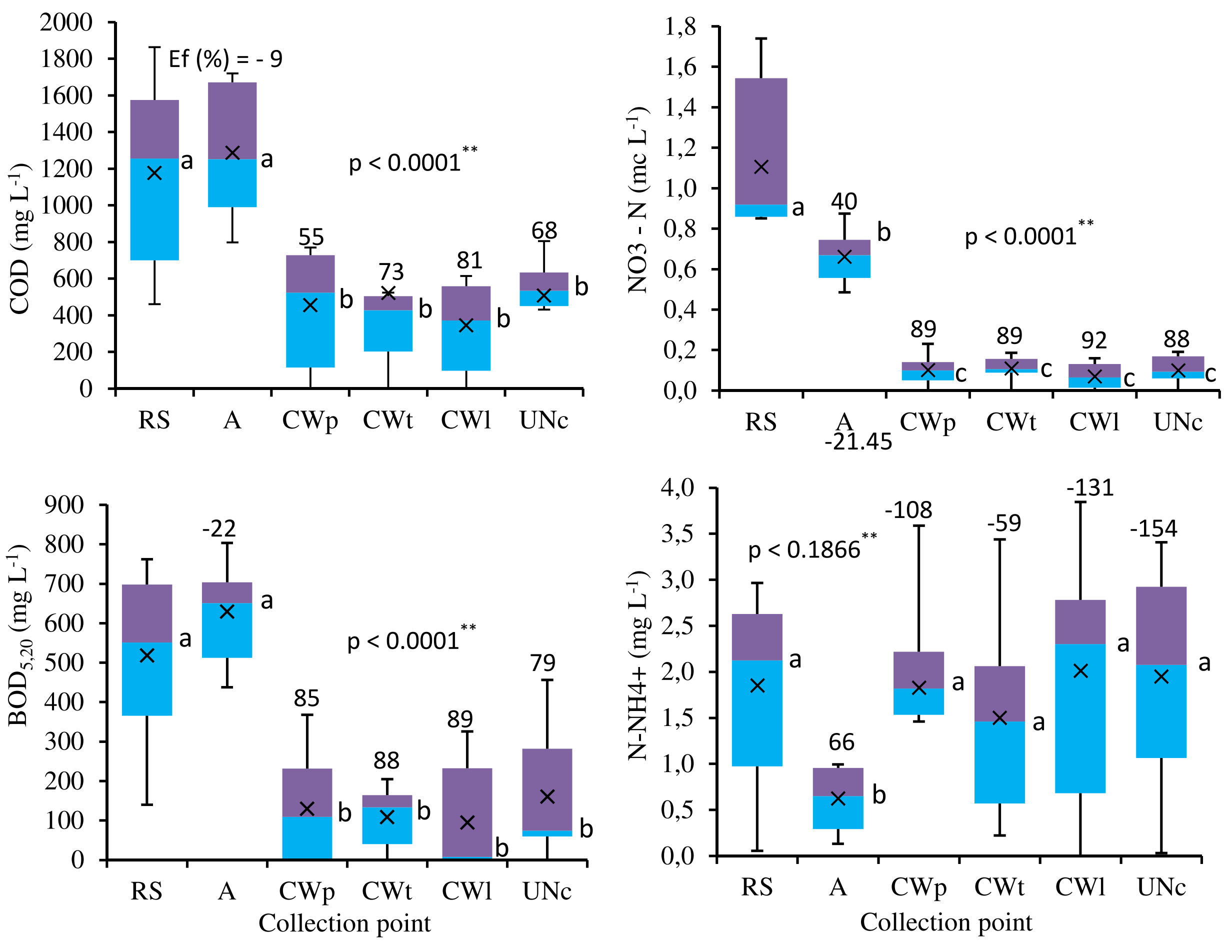

Figure 6. Box-plot of values of biochemical oxygen demand ($BOD_{5,20}$), chemical oxygen demand (COD), nitrate (NO_3^-), ammonium nitrogen ($N\text{-}NH_4^+$), SD, CV, and Ef, and test of comparison of means between the points evaluated in the sewage treatment plant. Where: RS: raw sewage, A:influent to CW; CWt: bed effluent grown with cattail; CWp: bed effluent grown with piripiri; CWl: bed effluent grown with white garland lily; UNc: effluent from uncultivated bed. Ef: efficiency between influent and effluent in CW and UNc: **significant by Duncan test at 5% probability

In the effluent of CWt, CWp, CWl and UNc, the Ef in relation to A was of 75, 73, 81, and 68% of COD (Figure 6), respectively. In absolute values, the UNc presented the lowest Ef, which is due to the lack of root system of macrophyte plants. It influencedCWdue to the formation of a biofilm in the support medium and in plant roots, favoring the removal of organic and inorganic particles. However, this did not occur in the present study as on average the same values were obtained for planted and not planted treatments, as the flow of the influent occurred primarily in the lower half of the CW, where there were practically no roots. Possibly, the roots were not able to penetrate the support medium towards deeper layers. Ali *et al.* (2018) monitored its response to domestic sewage treatment under variable continuous flow using an anaerobic reactor followed by a subsurface horizontal flow CWthroughout one year and observed an overall maximum decrease of 78% in COD.

$BOD_{5,20}$ represents an adequate indicator of biodegradable organic matter in domestic sewage. $BOD_{5,20}$was higher in A (629.3 mg L^{-1}),with a CV of 19.1% $BOD_{5,20}$ in relation to RS (518.1 mg L^{-1}), which had a CV of 40.6%, which increased 22% due to the same reasons presented for the COD (Figure 6). Ali *et al.* (2018) observed in RS

$BOD_{5,20}$ concentrations ranging from 60 to 200 mg L^{-1} depending on the water used by the community during the study period. However, in the effluent of CW and UNc, there was a reduction in relation to the A, reaching 89% in CWl. It was however lower than that Silva *et al*. (2015) obtained (97 to 99%) especially because of the association of the use of coarse sand, gravel, and crushed gravel in a same CW. In this study, only gravel #2 was used as a support medium, which resulted in high efficiency in the removal of suspended and sedimentable solids, although allowing the passage of particulate organic matter, which could be greatly increased by using a support medium consisting of sand, as stated by Silva *et al.* (2015), and consequently, of particulate BOD.

Ali *et al*. (2018) had already observed an overall maximum decrease of 82% in $BOD_{5,20}$. Even so, the results corroborate Brasil (2011), which recommended a $BOD_{5,20}$ limit of 120 mg $L^{-1}$and a minimum removal efficiency of 60% for the discharge of treated sewage in class 2 water courses.

Was observed that the nitrate content in RS was 1.10 mg L^{-1}, which was higher than that obtained for A (0.7 mg L^{-1}). The reduction of 40% was observed (Figure 6), similar as that Ali *et al*. (2018) observed. The authors reported that the nitrate content ranges from 0.0 to 4.3 mg N L^{-1} in RS. They also observed that after going through the anaerobic reactor, there was initially a 10 to 20% reduction, but it increased to 53% over time at concentrations ranging from 0 to 3.2 mg L^{-1}.

The effluent of CWt, CWp, CWl and UNc were equal, but significantly lower than RS and A, with an Ef of 89, 89, 92, and 88%, respectively, but with a CV reaching 87% for CWl (Figure 6), was favored as the CW and UNc are anaerobic/anoxic environments. Ali *et al*. (2018) also observed a reduction of up to 46% after going through the subsurface flow CW. Zhang *et al*. (2016) found that the CW cultivated with M. *aquaticum* increased the Ef of total nitrogen by 51%, and A. *philoxeroides* increased 36% more than the control treatment (without plants).

The mean value of ammonium nitrogen in RS was 1.83 mg L^{-1}, thus higher than A (0.63 mg L^{-1}), i.e., a reduction of 66%. However, it was the same among the effluents of CW. There were decreases of 1.8, 1.5, 2.0, and 2.0 mg L^{-1} in relation to the A of 108, 59, 131, and 154% for CWt, CWp, CWl and UNc, respectively (Figure 6). The low concentration of ammonia may be related to the reduction in the concentration of organic matter in the sewage, as it is primarily derived from a cafeteria and, to a lesser extent, from sewage of toilets. Ammonium nitrogen values showed high fluctuations between collection dates at all evaluated points. The lowest CV was for A (57.8%), while the highest CV was for CWt (73.5%), which occurred due to the great variability in the composition of raw sewage, which at some times of the day was generated primarily in the restaurant and at other times generated in toilets, and also occurred due to the non-equitable use of the CW during the day; The use of a higher HRT is a possibility to reduce variability, as according to Nivala *et al.* (2019), the presence of the ammonia ion is directly related to the concentration of solids in the sewage.

Ammonium nitrogen volatilization is a low physicochemical process at a pH below 8.0 (REDDY; D'ANGELO, 1997), as in the study (7.40), but high at a pH greater than 8.0. According by the ammonium decrease was mainly attributed to the absorptionby plants and microbial activities (HE *et al*., 2018).

At the same time, nitrification and denitrification are processes that contribute to the biological removal of ammonium nitrogen, transforming it into nitrite and nitrate and volatile gases, reactions that occur in both anaerobic and aerobic conditions. Thus, in this study, the low efficiencies of NH_4^+-N are related to its accumulation in the environment during the treatment process. In addition, the environment did not show any variation in the redox potential, and therefore nitrification did not occur, promoting the denitrification of the nitrate coming from of the influent. According to Prinčič *et al.* (1998), for nitrification, the optimal pH is between 6.5 and 8.5, which occurred only in the affluent. However, in the effluent, the pH is favorable to the removal of NH_4^+-N, resulting in low values in the effluent. For He *et al*. (2018), the removal efficiency of NH_4^+-N was significantly correlated with temperature, decreasing in summer probably as the high temperature inhibited the activities of the nitrifying bacteria, hence inhibiting nitrification. Another important reason related to the decrease of NH_4^+-N removal at high temperatures was the evapotranspiration, which condensed the wastewater. This fact was observed in this study, including at the UNc, since there was evaporation in this study.

The hydraulic retention time (HRT) presented a strong Pearson's linear correlation (r) (categorization suggested by Callegari-Jacques (2007) as r = 0, null; 0 to 0.30, weak; 0.3 to 0.6 moderate; 0.6 to 0.9, strong; 0.9 to 1, very strong; and 1, perfect) in relation to turbidity (0.85), TSS (0.80), SS (0.70), COD (0.83), $BOD_{5,20}$ (0.76), and NO_3^- N (0.84). The same was observed by Rabello *et al*. (2019). This can be explained both by the longer time needed for the microorganisms present in the biofilms to act, so that they would be able to biotransform and biodegrade the compounds (TRAN *et al.* 2013); and by the fact that bioaccumulation by the plants is possible, as long as toxic levels are not reached (BARTRONS; PEÑUELAS, 2017). PET presented a strong positive correlation with turbidity (0.60), COD (0.74), $BOD_{5,20}$ (0.81). N-NH_4^+(0.81) andPO_4^{3-}(0.86)had a strong positive correlation only with pH. According to Wang *et al.* (2012), the reduction of N-NH_4^+ depends on bacterial communities and the water chemistry, such as pH, temperature, and oxygen concentrations that influence the process. According to Reddy and D'angelo (1997), ammonia volatilization is favored at pH > 8. In our study, the influent pH value was 5.7, suggesting non-appropriate conditions for ammonia volatilization. For the other attributes, in general, the correlation was negative or weak due to the reasons explained above.

Turbidity showed the greatest strong or very strong positive correlations with TSS, TS, COD, $BOD_{5,20}$ and NO_3-N, with values of 0.96, 0.84, 0.92, 0.89 and 1.00, respectively. This also occurred with TSS in relation to TS, COD, $BOD_{5,20}$, and NO_3^- N. COD correlated with DBO and NO_3^- N, with values of 0.99 (very strong) and 0.88 (strong) (Table 4).

According to Sérvulo *et al*. (2019), water losses due to evapotranspiration during treatment occur at rates greater than the absorption or retention of these impurities by plants. This reinforces the high correlation, for example, of PET with TS levels, which reinforces the need to use models that consider the balance between the volume of effluent in and out to determine removal efficiency indexes. The authors also noted that HRT had a negative linear relation with Na concentration and turbidity in CW with cattail, piripiri, and lobster-claws.

Thus, after applying the Pearson correlation to the values of efficiency indexes of the attributes evaluated, was observed that pH presented a very strong positive correlation with N-NH_4^+ (0.91), turbidity with COD (0.94), TS with CE (0.92), and $BOD_{5,20}$ (0.92) and COD with NO_3^- N (0.97) (Table 4).

Table 4. Pearson's correlations of mean values and efficiency of attributes analyzed in the effluent of CWp, CWt, CWl, and UNc

Correlation of average efficiency values												
Attribute	HRT	PET	EC	pH	Tur.	TSS	TS	COD	$BOD_{5,20}$	NO_3^-N	N-NH_4^+	PO_4^{3-}
HRT	**1.00**											
PET	0.25	**1.00**										
EC	-0.61	-0.27	**1.00**	0.72	0.55	-0.82	0.92	0.42	0.74	0.2	0.88	0.43
pH	-0.63	-0.83	0.19	**1.00**	0.17	-0.28	0.69	0.28	0.77	0.19	0.91	0.35
Tur.	0.85	0.60	-0.83	-0.69	**1.00**	-0.32	0.79	0.94	0.74	0.84	0.15	-0.48
TSS	0.80	0.44	-0.95	-0.47	0.96	**1.00**	-0.59	-0.03	-0.25	0.22	-0.63	-0.65
TS	0.70	0.18	-0.99	-0.19	0.84	0.95	**1.00**	0.74	0.92	0.57	0.72	0.04
COD	0.83	0.74	-0.55	-0.92	0.92	0.78	0.56	**1.00**	0.83	0.97	0.11	-0.64
$BOD_{5,20}$	0.76	0.81	-0.51	-0.94	0.89	0.74	0.50	0.99	**1.00**	0.74	0.63	-0.19
NO_3^- N	0.84	0.55	-0.88	-0.63	1.00	0.98	0.88	0.88	0.85	**1.00**	-0.06	-0.79
N-NH_4^+	-0.32	-0.51	-0.40	0.81	-0.18	0.10	0.37	-0.54	-0.58	-0.09	**1.00**	0.63
PO_4^{3-}	-0.27	-0.67	-0.33	0.86	-0.24	0.04	0.33	-0.59	-0.65	-0.15	0.98	**1.00**
Correlation of mean values of attributes												

CONCLUSIONS

- The potential evapotranspiration in CWt, CWp, and CWl was 2.45, 3.04, and 2.34 mm d^{-1}, corresponding to 42.5, 114.1, and 64.8%, respectively, thus being higher in relation to that in UNc.
- The pH was higher in the effluent of CWp, CWt, and CWl in relation to the raw sewage and the influent. The presence of macrophytes did not interfere in the EC.
- The values of TSS, $BOD_{5,20}$, COD, and nitrate in the effluent of CWp, CWt, CWl and UNc were lower in relation to those of the influent, while ammonium nitrogen and total phosphate were higher.
- Piripiri and cattails showed the better development of plants in the second half of constructed wetlands, but the macrophyte white garland lily did not develop properly to the composition of sewage treaded.
- The STS efficiency indexes showed very strong positive Pearson correlations (> 90%). Correlations above 90% were pH with$N\text{-}NH_4^+$, turbidity with COD, TS with EC, and $BOD_{5,20}$ and COD with NO_3^-.

AUTHORSHIP CONTRIBUTION STATEMENT

SANDRI, D.: Formal Analysis, Methodology, Resources, Supervision, Writing – review & editing; **REIS, A.P.:** Conceptualization, Formal Analysis, Investigation, Methodology, Writing – original draft.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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