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Performance of sewage treatment plant with septic tank, anaerobic filter and constructed wetland with *Typha* spp

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Paulo Fortes Neto[1*]; Nara Lucia Perondi Fortes[1]; Elizabeth da Costa Neves Fernandes de Almeida Duarte[2]; Rita do Amaral Fragoso[2]; Ana Catarina Marcos Henriques[2]; Sofia Helena Lewis Lopes[2]; Luiza Fernanda dos Santos Pereira[1]

[1]Departamento de Ciências Agrárias. Universidade de Taubaté (UNITAU), Est. Mun. Dr. José Luiz Cembranelli, n° 5000, CEP: 12081-010, Taubaté, SP, Brazil.
E-mail: narapfortes@gmail.com, luiza.pereira@taubate.sp.gov.br
[2]Instituto Superior de Agronomia (ISA). Universidade de Lisboa (ULISBOA), Lisboa, Portugal.
E-mail: eduarte@isa.ulisboa.pt, ritafragoso@isa.ulisboa.pt, anac.henriques@gmail.com, sofialewisl@outlook.com
[*]Corresponding author. E-mail: paulo.fortes@unitau.com.br

ABSTRACT

The study reports the performance of a sanitary effluent treatment constituted by a septic tank, anaerobic filter and constructed wetland. The study monitored nutrient's, carbonaceous material's and thermotolerant coliform's (CT) removal efficiency during 12 months. The treatment system included a septic tank, an anaerobic filter and a horizontal subsurface flow constructed wetland cultivated with *Typha* spp. Effluent samples were monthly collected before and after the septic tank, anaerobic filter and wetland. The removal efficiency for $N\text{-}NH^{+}_{4}$ was 37.6%, 66.3% for total P, 37% for COD, 54% for BOD and 99.4% for CT. The anaerobic filter and wetland were more efficient than the septic tank. P-total reduction was higher in the constructed wetland than in the anaerobic filter. Climatic conditions influenced the evaluated constituent's removal being the highest values during hot months.

Keywords: constructed wetland, macrophytes, nutrient removal.

Desempenho do tratamento de esgoto com tanque séptico, filtro anaeróbico e wetland construído com Typha spp

RESUMO

O objetivo desta pesquisa foi avaliar o desempenho do tratamento do esgoto sanitário, no que se refere à remoção de nutrientes, material carbonáceo e coliformes termotolerantes, durante 12 meses de monitoramento. O sistema de tratamento era composto por um tanque séptico, filtro anaeróbio e wetland construído com escoamento horizontal subsuperficial cultivado com Typha spp. As amostras do efluente foram coletadas mensalmente antes e após passar pelo tanque séptico, filtro anaeróbio e wetland. A partir das análises realizadas, notou-se que a eficiência do sistema na remoção para N-NH+4 foi de 37,6%; 66,3% para P-total; 37% para DQO; 54% para DBO e 99,4% para coliformes termotolerante. Em relação ao desempenho das fases, foi constatado que o filtro anaeróbio e o leito cultivado foram mais eficientes na redução do que o tanque séptico. A redução de P-total foi mais acentuada no wetland construído do que no filtro anaeróbio. A remoção dos constituintes investigados foi influenciada pela condição climática, sendo os maiores valores observados no período de verão e os menores no período de inverno.

Palavras-chave: macrófitas, remoção de nutrientes, wetland construído.

1. INTRODUCTION

The system of treatment of sanitary effluents with macrophytes can be developed in a natural or artificial way. Natural systems are humid habitats, or wetlands is a term used to define large wetlands, where periodic or permanent flooding may occur. Thus, saturated soil provides an environment conducive to aquatic plants, microorganisms and animal's development (Kadlec and Wallace, 2009). The artificial systems, called constructed wetlands, are engineered systems that have been designed and constructed to mimetize the natural processes involving wetland vegetation, soils and microbial communities for wastewater treatment (Calijuri *et al.*, 2009).

Constructed wetlands (CW) are widely applied as a low-cost alternative or complementary system for wastewater treatment, having the advantages of low maintenance and ease of operation (Russo *et al*., 2019). CW can be used in primary, secondary and tertiary treatment of household, industrial and rural wastewater; groundwater and water for reuse; sludge management or runoff waters (Zhang *et al*., 2015). However, most of the work developed in Brazil uses CW as a secondary treatment step, used in post-treatment of decant-digester, septic tank type, compartmentalized anaerobic reactor, anaerobic sludge blanket (UASB) reactors or anaerobic ponds (Sezerino *et al*., 2015).

Like any other treatment process, the use of plants in the wetland is intended to reduce contaminants levels to ranges of safe and compatible limits with respect to the protection of human health or to prevent the spread of harmful substances to the environment (Brix and Arias, 2005; Sezerino *et al*., 2015). Among the macrophytes, *Typha* spp stands out as the most used in the cultivated bed, followed by *Eleochanis* spp and *Zizaniopsis* spp (Sezerino *et al*., 2015).

The wetland's efficiency for wastewater treatment is variable and depends on chemical and microbiological composition of the effluent, flow rate, time of hydraulic detention, plant species and filtering media (Machado *et al*., 2016; Meyer *et al*., 2013). Bregunce *et al*. (2011), used a system planted with *Sagittaria montevidensis* and verified that the removal of volatile suspended solids (VSS) efficiency was 63%. On the other hand, Souza *et al*. (2004) and Barreto (2005), using a system planted with *Thypha* spp, obtained removal values of 52% and 31% respectively. Regarding the efficiency in organic matter removal expressed in chemical oxygen demand (COD), Brito (2005), used an elephant grass bedding system (*Pennisetum purpureum*), and Barreto (2005), with *Typha* spp, and showed a mean removal efficiency of 53%. Ribas and Fortes Neto (2008), studying the *Typha* spp macrophyte in the bed, had an 89% reduction in COD. Concerning he to total phosphorus (P-total), Mazzola *et al*. (2005), evaluating the efficiency of *Typha* spp and *Eleocharis* spp, found a reduction in that *Typha* spp reduced the total P content by 30% and 11% respectively. According to these authors, this fact may be associated with the different free phosphorus, plant absorption, as *Typha* spp presented a high growth rate and biomass production (leaves and roots) during the period of analysis. In relation to the removal of nitrogen compounds, specifically reduction of ammonia ($N\text{-}NH_4$), most of the literature effluent values for the constructed wetland, report a varied removal, between 30 and 60% (IWA, 2000). According to Kadlec and Wallace (2009), the main mechanism of nitrogen removal in the wetland is the biochemical pathway, known as nitrification followed by denitrification. However, other removal mechanisms may contribute to the reduction of $N\text{-}NH_3$

N- NH_4, such as adsorption on the filter material, uptake and immobilization by macrophytes roots as well as dilution by pluviometric precipitation. The wide range of P-total and N-NH_3 N-NH_4^+ removal values in the wetland concerns the plants vegetative cycle and climatic variables (Calijuri *et al*., 2009).

In evaluating the efficiency of the constructed wetland system, one must also take into account the removal of pathogenic microorganisms, generally indicated by the presence of thermotolerant coliforms. Regarding the removal of thermotolerant coliforms, several studies show range between 86% and 99%, and these values vary according to macrophyte species. This is due to the inhibition of pathogenic microorganism's growth microorganisms by the macrophytes rhizosphere microorganisms (Brix, 1997; Ribas and Fortes Neto, 2008). The thermotolerant coliforms reduction also occurs due to the filtration mechanism, to the fixation of biofilms in the medium and the roots of macrophyte roots toxic substances and antibiotics release and predation by nematodes and parasites (Souza *et al*., 2004; Almeida *et al*., 2010).

Most of the studies carried out to assess the efficiency of the constructed wetland in nutrient removal, organic load and thermotolerant coliforms were carried out under pilot project conditions and with a short monitoring period. The present work objective was to verify the constructed wetland performance in real operational scale, in terms of nutrient (nitrogen and phosphorus), carbonaceous material and thermotolerant coliforms removal along 12 months of monitoring.

2. MATERIALS AND METHODS

The experiment occurred at the Sewage Treatment and Wastewater Treatment Unit of the, Agrarian Sciences Department - University of Taubaté, Taubaté (Brazil). The sewage treatment plant (STP), consisting of a septic tank followed by an upflow anaerobic filter and a sub-surface flow wetland. The septic tank and the anaerobic filter were constructed according to NBR 7229 (ABTN, 1993) and the CW cultivated bed was dimensioned according to the specifications stipulated by Philippi and Sezerino (2004).

The septic tank was constructed in a rectangular form (5.4m long, 3.5m wide, 1.6m high and a total volume of 30.24m^3) and with a 10 days hydraulic residence time (HRT). The upflow anaerobic filter was constructed in a circular format (3m diameter, 2m high and 6m^3 total volume) and 2 days HRT. The CW was built in cylindrical format (3m in diameter, 2m high and 6m^3 in total volume) with gravel as filling medium and using *Typha* spp with 4 plants/m^2 and constructed in one and a two HRT.

Figure 1 shows the general layout of the STP, with a flow rate of 3.0 m^3 average standard deviation day^{-1}, 14-days of HRT and four monitoring points.

The evaluation of the STP performance was carried out between April 2009 and March 2010 after wetland cultivation, with effluent samples collected three times a week, always at 9:00 am, in two collection points: P1 -influent and P4-effluent. For the evaluation of treatment stages performance, monitoring was carried out during December 2009 and effluent samples collected at four points: P1-influent, P2-septic tank effluent, P3-effluent post- anaerobic filter and P4-effluent from CW bed (Figure 1). Effluent samples were kept in sterilized glass containers under refrigeration until analysis in the Water and Effluent Laboratory of the Civil, Environmental and Sanitary Engineering Department -University of Taubaté. The analyzed variables were: ammoniacal nitrogen (N-NH_4^+), total phosphorus (P-total), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5) and thermotolerant coliforms (TC). Laboratory tests were performed in accordance with Standard Methods for the Examination of Water and Wastewater (APHA, 2000). Total nitrogen, total phosphorus (P-total), chemical oxygen demand (COD), biochemical oxygen demand (BOD) and thermotolerant coliforms

(TC) results, determined in the four collection points, were submitted to descriptive statistics for average and dispersion values determination.

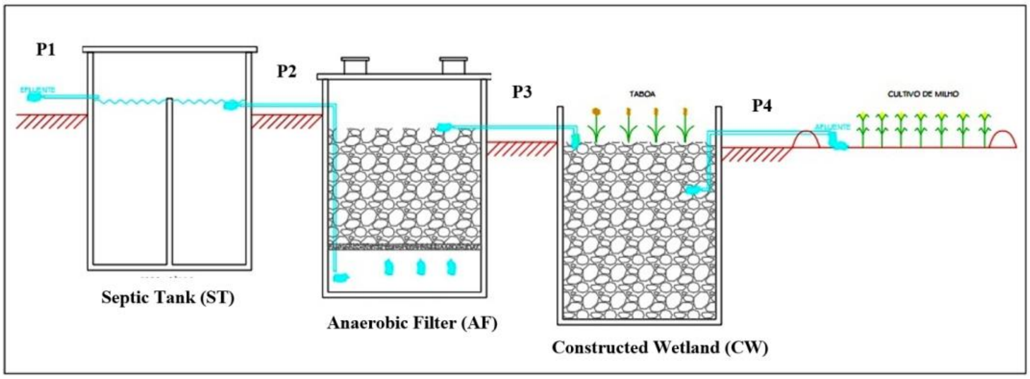

Figure 1. Sewage treatment plant (STP) components and collection points, P1 to P4 (without scale).

3. RESULTS AND DISCUSSION

3.1. Sewage treatment system overall performance

Table 1 shows the results of the effluent samples analyzed variables collected at the entrance and exit of the sewage treatment plant (P1 and P4). It is observed that the levels of N-NH^{+}_{4}, P-total, COD, BOD and thermotolerant coliforms are reduced after passing through the treatment system. Removal efficiencies were: 99.4% for thermotolerant coliforms, 66.3% for P-total and 54.0% BOD_5, 37.6% for N-NH_4^+ and37.0% COD.

Table 1. Mean values, standard deviations and removal efficiencies during the monitoring of the sewage treatment system between April 2009 and March 2010.

Variables	Collection Points		Efficiency
	P1	P4	(%)
N-NH^{+}_{4} (mg L^{-1})	49.6 ± 4.8	31.2 ± 8.5	37.6
P-total (mg L^{-1})	31.5 ± 4.3	10,6 ± 3,7	66.3
COD (mg L^{-1})	139.9 ± 15.1	88.1 ± 12.4	37.0
BOD_5 (mg L^{-1})	88.9 ± 9.7	40.9 ± 11.9	54.0
Thermotolerant coliforms (NMP 100 mL^{-1})	101 ± 15.7 x 10^3	5.4 ± 2.3 x 10^2	99.4

BOD_5 mean removal values, P-total and thermotolerant coliforms were within the range considered adequate for sewage treatment with septic tank followed by sand filter, and the removal of N-NH_4^+ was within the range expected for the septic tank treatment in conjunction with aerobic filter. On the other hand, the COD result was below the minimum limit established for all forms of treatment used after the effluent passes through the septic tank (ABNT, 1997). Comparing the results with those from the literature, for N-NH_4^+ removal, values were within the 33% and 38.6% range (Olijnyk, 2007; Assumpção *et al*., 2011; Mazzola *et al*., 2005) and below 78% upper limit (Avelar, 2009). The COD and the BOD_5 were below the 57% to 98% and 61% to 97% range, respectively (Sezerino, 2006; Olijnyk 2007; Roche *et al*., 2008). In addition, the thermotolerant coliforms were in the range of 90 to 99.9% (Calijuri *et al*., 2009). This wide range of removal values found in the literature relates to different conditions in which the studies were carried out, such as: effluent composition; effluent flow, hydraulic residence time and monitoring period; (Almeida *et al*., 2010, Assumpção *et a*l., 2011).

Figure 2, the removal efficiency of N-$NH^{+}_{4,}$ P-total, COD, BOD and thermotolerant coliforms observed during the monitoring period between April 2009 and March 2010 is shown. It is noted that efficiency of thermotolerant coliforms remains constant and above 90% during the whole monitoring period, followed by the total P-upward trend with few oscillations in the removal, with values always above 50%.

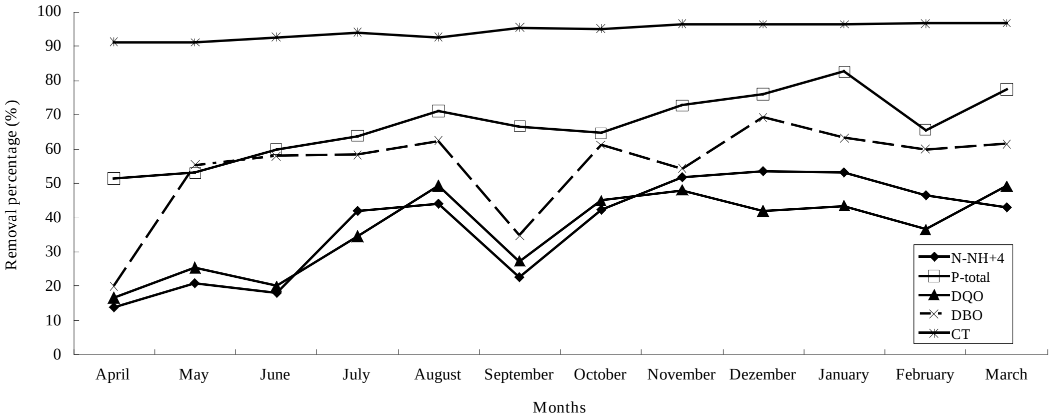

Figure 2. Variation of $N\text{-}NH_4^+$, P-total, COD, BOD and thermotolerant coliforms (TC) in effluent samples collected after passing through the CW bed during the months of April 2009 to March 2010.

On the other hand, the behavior profile of COD, BOD_5 and $N\text{-}NH_4^+$ was similar with a sharp removal decrease in September 2009. Afterwards, there was an increase of removal values, to values, higher than those determined between April and September 2009.

The trend representing the removal of COD, BOD_5 and $N\text{-}NH_4^+$ (Figure 2) suggests that something occurred in September 2009 effluent that inhibited microorganisms activity in the treatment system, since the variables relate to the process of biodegradation of the organic fractions present in sanitary sewage (Kadlec and Brix, 1995).

In general, with the exception in September, there were no significant fluctuations observed with the cycles of fall and yield gain in the $N\text{-}NH_4^+$, P-total, COD, BOD_5 and thermotolerant coliforms (TC), probably because the treatment was still in the second year of operation. In this regard, some authors report that the removal efficiency of nutrients, organic matter and thermotolerant coliforms tends to be higher at the beginning of the process but reduces with the operation time of the sewage treatment system (Souza *et al*., 2004; Calijuri *et al*., 2009).

The temperature may have been another important factor that influenced the $N\text{-}NH_4^+$, P-total, COD, BOD_5 and TC thermotolerant coliforms removal. When analyzing the relationship between the periods of cold months (April to September/2009) with hot months (October/2009 to March/2010) in terms of efficiency in the reduction, it is noticed that the removal rate of the variables analyzed were influenced by the conditions related to temperature (Figure 3). The removal values were higher in the warm months than in the cold months, and the variables $N\text{-}NH_4$, COD, BOD_5 and P-total were more sensitive to climatic variation than thermotolerant coliforms.

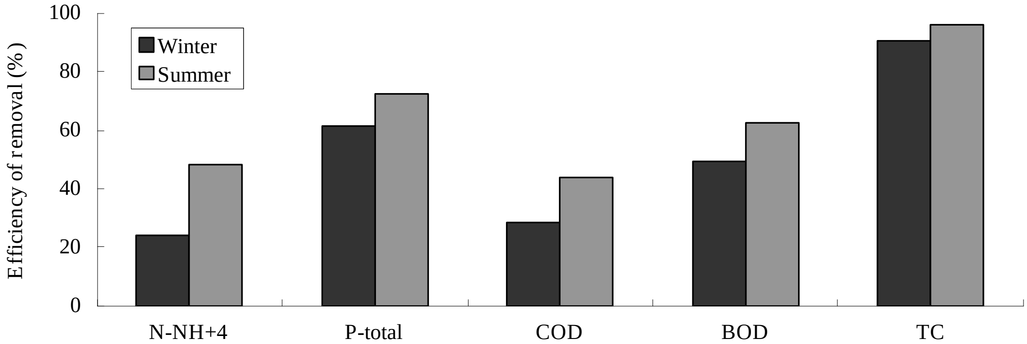

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Figure 3. Efficiency of N-NH_4^+, P-total, COD, BOD_5 and thermotolerant coliforms (TC) removal in effluent samples collected during periods of cold and hot months between April 2009 and April 2010.

3.2. Phases performance of the phases of the sewage treatment system

Calijuri *et al*. (2009) treated effluent samples from an upflow anaerobic reactor system with CW with *Typha* spp. and showed that for the total P and total coliform the removal efficiency was higher in the warmer months than in the colder months. In this respect, Andrade (2012), evaluating the performance of *Canna generalis* in the treatment of sewage, found that temperature could accelerate or delay the plants development and microorganisms and, consequently, influence process efficiency. Bahgat *et al*. (1999) state that, in wetland cultivated systems, the biological activity is directly influenced by the ambient temperature, which, when elevated, can increase the microbial activity in nutrient removal and organic load of the effluent.

Figure 4 shows the efficiency of N-NH_4^+, P-total, COD, BOD and thermotolerant coliforms removal by each treatment phase. The lowest removal values for all the variables were found in the effluent after passing the septic tank. Subsequently, the removal efficiency increases in the anaerobic filter and CW. The high capacity of nutrient removal, organic load and pathogenic microorganisms determined in the wetland cultivated confirm the hypothesis of its use in the post-treatment of anaerobic effluents (Brito *et al*., 2005; Avelar *et al*., 2009; Sezerino *et al*., 2015).

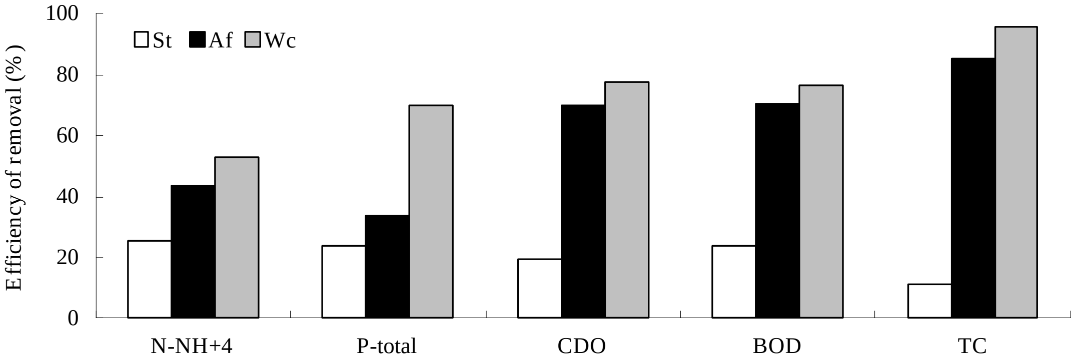

Figure 4. Phases Performance of treatment system in the removal of N-NH_4^+, P-total, COD, BOD_5 and thermotolerant coliforms (TC) determined in samples collected before and after the septic tank (St), anaerobic filter (Af) and constructed wetland (Wc).

Removal of N-NH_4^+ in the septic tank was 25.7%. This value was within the mean verified by other authors who found reductions varying between 3% and 39% (Oliveira and Von Sperling, 2005; Luna *et al*., 2013). The mean percentage of COD removal and BOD_5 in the septic tank was 19.6% and 23.9%, respectively. These values are below the observed in other studies with an average removal ranging from 30% to 55%. Thus, Colares & Sandri (2013), analyzing the efficiency of sewage treatment with septic tank followed by CW bed, found an efficiency of 23.58% for COD and 42.34% for BOD. Jordão and Pessoa (2011) observed a 35% to 65% removal in the BOD values of septic tank effluent; and Borges (2008) verified an average 52% removal in single-chamber septic tank effluent. The efficiency of the N-NH_4^+ removal in the anaerobic filter effluent was 43.8%. However, it is important to note that this high removal rate may be associated to the nitrification, immobilization and volatilization processes of N-NH_4^+ by the microorganisms adhered to the biofilm and to the filter media pores (Lamego and Costa, 2011).

As for the action of the anaerobic filter in the P-total removal (Figure 4), it can be stated that it was efficient, providing a removal of 34%, compatible with the removal value range

(20% a 50%) stipulated by ABNT (1997). According to Prochaska and Zouboulis (2003), incorporation of phosphorus into the biofilm is an important removal mechanism in anaerobic filters, due to the phosphorous participation in microorganism's metabolism and its consequent immobilization and accumulation in the microbial biomass.

The anaerobic filter showed a high COD and BOD_5 removal, with mean values of 70% and 70.7% respectively, results that are within the range considered adequate for the removal of pollutants, when the septic tank is followed by the anaerobic filter (ABNT, 1997). The values are also consistent with the efficiency range observed by several authors. For example, Calijuri *et al*. (2009) found values of COD removal ranging from 69% to 75%, and BOD_5 between 77% and 84% (TDH = 7 hours). Tonetti et al. (2010) found an average removal of 76 ± 12% COD and 71 ± 15% BOD (TDH = 9 hours). The high efficiency in the removal of COD and BOD_5 in the anaerobic filter can be associated to the HRT, which in this case was 48 hours, well above the recommended 12 hours by NBR 7.229 (1993).

Regarding the thermotolerant coliforms removal, there was an expressive reduction of 85.2%, when compared to the 11.1% verified in the septic tank. This value of is similar to that observed by Cavalcante et al. (2010) that, studying the anaerobic filter sanitary efficiency, found a removal of 83.4%. Pereira-Ramirez *et al*. (2004), using an anaerobic filter in the post-treatment of an anaerobic flow reactor, determined thermotolerant coliform´s removal ranging from 80% to 96%.

The $N\text{-}NH_4^+$ removal, after the CW, was 52.9%. This value was higher than that observed in the septic tank and in the anaerobic filter (Figure 4). The high removal of $N\text{-}NH_4^+$, after the CW bed, occurs due to the nitrification and immobilization processes of ammonia carried out by the microorganisms in the rhizosphere of *Typha* spp, and also by the plant absorption, which roots are adhered to the filter medium used to fill the cultivated bed (IWA, 2000; Olijnyk *et al*., 2007). The $N\text{-}NH_4^+$ removal observed in the present study for the CW bed is in accordance with reference values observed by several authors in effluent samples treated in bed systems with different species of macrophytes (Souza *et al*., 2004; Brasil *et a*l., 2005; Avelar, 2009).

The cultivated bed was more efficient in the P-total removal when compared to the septic tank and anaerobic filter, with a value of 69.8% (Figure 4). This value was above literature values observed by Mazzola *et al*. (2005) and Assumpção *et al*. (2011) in domestic effluent samples treated in a *Typha* spp CW bed. These authors verified that the average efficiency for the P-total removal ranged from 20% to 25.6%. On the other hand, it was below the value reported by Avelar (2009), who evaluated a CW filled with steel slag using *Typha* spp. for P-total removal efficiency and found a 78% removal. Also Campos *et al*. (2002) reported a 95% phosphorus removal in treated slurry samples in CW with *Typha* spp.

These results suggest that the efficiency of P-total removal is associated with HRT, effluent flow rate, filter medium type of material, macrophyte species and development , adsorption in plant and microbiological biomass, precipitation of insoluble compounds and adsorption to the substrate (Campos *et al*., 2002; Mazzola *et al*., 2005; Avelar, 2009; Assumpção *et a*l., 2011).

The COD reduction was higher (77.8%) in the CW bed than in the other phases of the treatment process (Figure 4). The results were within the values verified by other authors who found, in similar studies, COD removals varying between 60% and 90% (e.g. Silva *et al*., 2004). The percentage of BOD_5 removal from the cultivated bed effluent was 76.4% (Figure 4). This result is below the values of 85% and 90.7% already observed by other authors under different conditions, such as HRT, macrophyte species and type of filter medium (Duarte, 2008; Avelar, 2009; Almeida *et al*., 2010). The reduction of COD and BOD_5 observed in the effluent, after the CW, may be associated with the presence of *Typha* spp, as Brix (1997) and Brix and Arias (2005) and transfer it to the rhizomes and roots through the aerenchyma, making the region of the rhizosphere that is located inside the filter medium aerobic. The oxygen transfer to the bed layer, located below the water sheet, increases the degradation of organic compounds by the microorganisms that inhabit the *Typha* spp rhizosphere (Brix, 1997). The removal of suspended organic matter, sedimentable or soluble in the CW bed also occurs through physical processes, such as sedimentation, due to the low flow rate and filtration, the presence of roots, rhizomes and the gravel used as a filter medium (USEPA, 1988).

Figure 4, shows the thermotolerant coliforms reduction in the effluent after the septic tank, anaerobic filter and CW bed. The CW had a 95.7% pathogenic microorganism's removal. This value is within the ones verified by several authors that used CW system for sanitary effluents treatment (Avelar, 2009; Calijuri *et al*., 2009; Almeida *et al*., 2010; Bregunce *et al*., 2011).

According to the study published by IWA (2000), the reduction of pathogenic microorganisms, in a system that includes CW in the final phase of treatment, occurs by the appropriate combination of physical, chemical and biological factors. For physical factors, filtration, exposure to UV and sedimentation are reported, concerning chemical reactions pathways factors, oxidation, exposure to biocides excreted by macrophytes roots and adsorption along organic fractions in the filter medium and in the rhizosphere are mentioned. In relation to the mechanisms of biological removal, the following are described: predation by nematodes and protozoa, attack by bacteria and viruses, and finally natural death (Sousa *et a*l., 2004; Brasil, *et al*., 2005; Almeida *et al*., 2010).

4. CONCLUSIONS

The sewage treatment system with septic tank, anaerobic filter and CW showed a high efficiency in the removal of thermotolerant coliforms (99.4%) and total P (66.3%), medium for BOD_5 (54.0%), and low for $N\text{-}NH_4^+$ (37.6%) and COD (37.0%).

The temperature influenced the sewage treatment performance in the reduction of $N\text{-}NH_4^+$, P-total, COD, BOD_5 and thermotolerant coliforms.

The lowest removal values for $N\text{-}NH_4^+$, P-total, COD, BOD and thermotolerant coliforms were in the septic tank and the highest in the anaerobic filter and CW.

The P-total removal was higher in the constructed wetland due to the phosphorus absorption by t *Typha* spp roots.

5. ACKNOWLEDGMENT

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