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To cite this document:
Daiane Cristina de Oliveira Garcia, Liliane Lazzari Albertin, Tsunao Matsumoto, (2017) "Use of a duckweed pond for the domestic wastewater polishing in Ilha Solteira, SP, Brazil", Management of Environmental Quality: An International Journal, Vol. 28 Issue: 4, pp.477-489, https://doi.org/10.1108/MEQ-07-2015-0138
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Use of a duckweed pond for the domestic wastewater polishing in Ilha Solteira, SP, Brazil

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Received 22 July 2015
Revised 29 September 2015
28 February 2016
Accepted 7 May 2016

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Abstract

Purpose – The purpose of this paper is to evaluate the efficiency of a duckweed pond in the polishing of a stabilization pond effluent, as well as quantify its biomass production. Once an adequate destination is given to the produced biomass, the wastewater treatment plant can work in a sustainable and integrated way.

Design/methodology/approach – The duckweed pond consisted of a tank with volume 0.44 m^3, operating in continuous flow with an outflow of 0.12 m^3/day and hydraulic retention time of 3.8 days. Effluent samples were collected before and after the treatment, with analyzes made: daily-pH, dissolved oxygen and temperature; twice a week – total nitrogen (TN), total phosphorus (TP) and chemical oxygen demand (COD); and weekly – total solids (TS) and Biochemical Oxygen Demand (BOD_5). The duckweeds were collected each for seven days for its production quantification.

Findings – The highest efficiency of TN, TP, COD, BOD_5 and TS removal were of 74.67, 66.18, 88.12, 91.14 and 48.9 percent, respectively. The highest biomass production rate was 10.33 g/m^2/day in dry mass.

Research limitations/implications – There was great variation in biomass production, which may be related to the stabilization pond effluent conditions. The evaluation of the effluent composition, which will be treated with duckweeds, is recommended.

Practical implications – The evaluated treatment system obtained positive results for the reduction in the analyzed variables concentration, being an efficient technology and with operational simplicity for the domestic effluent polishing.

Originality/value – The motivation of this work was to bring a simple system of treatment and to give value to a domestic wastewater treatment system in a way that, at the same time the effluent polluter level is reduced and it is also possible to produce biomass during the treatment process.

Keywords Duckweed-based wastewater treatment, *Landoltia punctata*, Stabilization pond

Paper type Research paper

1. Introduction

The necessity that Brazil has in improving and increasing the offer of wastewater treating and collecting services with attractive, efficient and low cost technologies is urgent. It may be shown through the data presented in the Basic Sanitation National Research made in 2008 (IBGE, 2008) which showed that only 28.5 percent Brazilian cities performed the treatment of wastewater collected.

An alternative treatment indicated is the use of stabilization pond system. However, to satisfy the launching patterns and preserve the water quality of the receptor body, the ponds effluents require an additional removal of nutrients. The use of a complex additional system for the extra removal of these nutrients does not make sense to the original conception of having a treatment with simple operation. Therefore, thinking of simple and efficient alternatives for the effluent polishing is necessary.

Management of Environmental Quality: An International Journal
Vol. 28 No. 4, 2017
pp. 477-489
© Emerald Publishing Limited
1477-7835
DOI 10.1108/MEQ-07-2015-0138

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The use of duckweed ponds has been efficient in searching for additional removal alternatives for organic matter, nutrients and even pathogens and metals.

The duckweeds have been widely and efficiently used in treating contaminated water for about 30 years, due to, among other factors, its capacity of adapting to a wide range of pH, temperature and nutrient concentration (Landolt and Kandeler, 1987; Fedler and Duan, 2011). This group of plants has great capacity of removing phosphorus and nitrogen compounds, as well as it reduces the concentrations of organic matter and suspended solids (Körner and Vermaat, 1998; Zimmo *et al.*, 2002; Xu and Shen, 2011; Mohedano *et al.*, 2014; De Matos *et al.*, 2014).

De Matos *et al.* (2014) achieved a reduction of 62.3 percent of total coliforms and 92.6 percent of *Escherichia coli* in domestic wastewater treated with duckweeds. Such removal occurs because duckweeds and bacteria compete for nutrients as well as due to the harvest process biomass.

Verma and Suthar (2015a), using *Lemna gibba* in domestic wastewater and different plant biomass density loads, managed removal of 67-89 percent nitrate, 85-86 percent of sulfates and 67-72 percent of total phosphorus (TP), in a period of 21 days.

Another characteristic of these vegetables, which draws attention, is their high growing levels and biomass production associated with an elevated nutritional value that can reach levels of 40 percent protein or more, according to what was indicated by Landesman *et al.* (2002). Depending on the environmental conditions, the biomass may double within only two days or less (Culley *et al.*, 1981).

The application potential of four duckweed genera (*Wolffia globosa*, *Lemna japonica*, *Landoltia punctata* and *Spirodela polyrhiza*) was compared by Zhao *et al.* The results indicated that each duckweed had unique potential advantages. *Lemna japonica* and *Landoltia punctata* may grow throughout the year, but *Spirodela polyrhiza* and *Wolffia globosa* do not survive cold weather. *Lemna japonica* was best in dry biomass production ($6.10\,g \cdot m^2 \cdot day^{-1}$), but also in crude protein (35.50 percent) and removal rates of TN and TP (0.66 and $0.089\,g \cdot m \cdot {}^2day \cdot {}^{-1}$, respectively). This demonstrates that *Lemna japonica* performed best in wastewater treatment and protein biomass production. Under nutrient starvation conditions, *Landoltia punctata* had the highest starch content (45.84 percent), dry biomass production ($4.81\,g \cdot m^2 \cdot day^{-1}$), making it best for starch biomass production.

The biomass production rate and biochemical composition depend on various factors such as the kind of specie used and the treatment conditions imposed. Verma and Suthar (2015b) present a summary about it.

The high production rate and the biochemical composition of biomass encourage the biomass production with great aggregated value. The duckweeds have been used as raw material for animal food production and as a potential source of biodiesel and ethanol (Cheng and Stomp, 2009; Mohedano *et al.*, 2012; Craggs *et al.*, 2012; Duan *et al.*, 2013).

Gathering the pointed aspects, it is noted that the necessity of access to wastewater collection and treatment is important for better population life conditions and also for the preservation of water resources. The stabilization ponds are viable alternatives to small communities with limited financial resources. Also, the duckweed ponds have been standing out for the effluent polishing actions. Simultaneously to the treatment process, it is possible to reuse the nutrients present in wastewater and produce biomass with great aggregated value and high protein load.

Therefore, this research aimed to evaluate the duckweed ponds efficiency in polishing domestic wastewater in Ilha Solteira, SP, and its valorization through the biomass produced as a byproduct.

2. Material and methods

The city of Ilha Solteira is located in São Paulo state northwest region, Brazil, at geographical coordinates 20°38′44′′ South and 51°06′35′′ West, with 25,064 inhabitants and has humid and subtropical climate, with mild and dry winter and hot rainy summer, with average annual temperature of 25.1°C and average rainfall of 1,305.8 mm.year^{-1} (Santos and Hernandez, 2013). The wastewater treatment plant (WWTP) in Ilha Solteira is comprised of two primary facultative ponds. The WWTP effluent was weekly collected and transported to the proposed pilot treatment system, which consisted of a storage tank, pump and duckweed pond (Figure 1).

The parameter used to dimensioning the pilot system was the hydraulic retention time (HRT). Some authors used high HRT, ranging from 15 to 29 days (Al-Nozaily *et al.*, 2000; Zimmo *et al.*, 2004; El-Shafai *et al.*, 2007). However, some authors have indicated that it is possible to obtain good removal efficiency with a low HRT (El-Kheir *et al.*, 2007; Ozengin and Elmaci, 2007; Penha-Lopes *et al.*, 2012). This research intended to test the treatment with low HRT.

The storage tank had a capacity of 1,200 L, from which the wastewater was pumped in a flow of 0.12 m^3.day^{-1} to the duckweed pond, with total used volume of 440 L, superficial area of 1.49 m^2 and depth of 0.31 m resulting in an HRT of 3.8 days.

The duckweeds specie used in this research was the *Landoltia punctata*, which is a native specie, whose strain is adapted to tropical and subtropical environment climatic conditions. The Laboratory of Liquid and Gaseous Effluents (Labeflu) of the Federal University of Santa Catarina provide samples plants.

To evaluate the treatment efficiency, wastewater samples were collected at the duckweed pond entrance and exit. The analyses of pH, dissolved oxygen (DO) and temperature were daily made; total nitrogen (TN), TP and total chemical oxygen demand (COD) were analyzed twice a week while the biochemical oxygen demand (BOD_5) and total solids (TS) weekly. The measurement of pH was conducted with a digital pHmeter bench (Digimed DM22 Model). The temperature was measured with a mercury thermometer. The other analysis methodologies used were depicted by APHA (2005). The adaptation period of the plants was 28 days. After this period, the laboratorial analyses were made between May 26, 2014 and August 6, 2014.

The number of plants placed in the tank at the beginning of the experiment was not quantified. It was placed in a manner that the whole surface stays covered by plants. The duckweeds forms a blanket on the surface of the water, preventing the penetration of solar light and production of algae.

For the quantification of the duckweed biomass produced, a PVC frame (20 × 20 cm) was introduced into the duckweed pond; it was floating and had an interior initial duckweed mass of 30 g (fresh weight). The biomass retained in the frame interior was collected each seventh day, weighed in high precision scale, dried for 24 hours at open environment, 24 hours in a stove at 60°C and weighed again.

The duckweeds productivity was evaluated starting by the relative growth rate (RGR), which relates the quantity of removed duckweeds to the area and time interval on which the growth happened, according to the Equation (1) (Mohedano *et al.*, 2012):

$$\mathrm{RGR} = \left(B_t/N\right)/A \tag{1}$$

RGR is the relative growth rate (g.m^{-2}.day^{-1}); B_t the total biomass removed in the period (g); N the number of days in the period; A the area (surface area of the frame) (m^2).

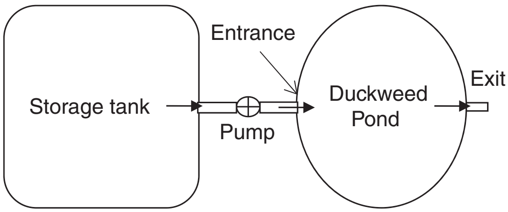

Figure 1. Configuration of duckweeds pond treatment system

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3. Results

While collecting data, the plants were subjected to the following climatic conditions: the maximum, minimum and average atmosphere temperatures registered were 34.5°C, 10.5°C and 22.3°C, respectively. The rainfall during the experimental period was 96.8 mm.

3.1 pH and temperature

Figure 2 shows the distribution of pH values and Figure 3 shows the registered temperature throughout the experimental period in the duckweed pond.

The maximum and minimum pH values at the entrance were 8.26 and 6.81 and at the exit were 8.22 and 6.84. Half of the data were between 7.01 and 7.57 at the entrance and 7.20 and 7.85 at the exit.

It is possible to notice that there was an increase in the pH value after the duckweeds treatment and that, although the pH values were higher at the exit, they were always within the ideal level for the growth of the plant.

According to Skillicorn *et al.* (1993), the duckweeds can survive in a pH level ranging from 5 to 9, but the best one for the growth is between 6.5 and 7.5. When the pH is lower than 7.0, the ammonia may be in its ionized state, as the ammonium ion, which is the plants favorite form. An alkaline pH changes the ion ammonium-ammonia

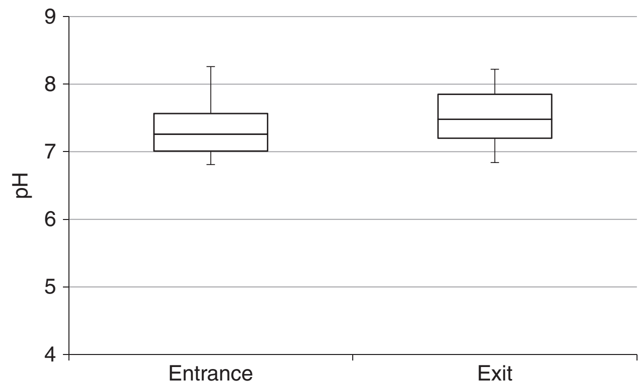

Figure 2. Distribution of pH values in duckweeds pond

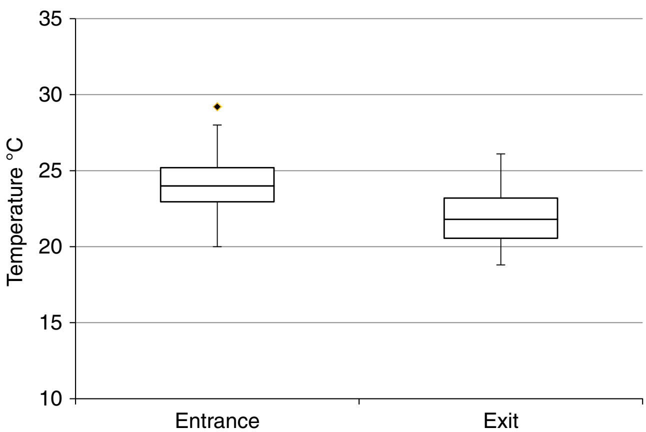

Figure 3. Distribution of temperature values in duckweeds pond

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balance into the non-ionized state releasing gaseous ammonia that is toxic to the duckweeds.

The wastewater temperature reduced between the entrance and the exit. According to Figure 3, 50 percent of the data are between 23°C to 25°C in the entrance and 23°C to 20.5°C in the exit.

This reduction in temperature values may be related to the covered duckweeds, which caused shadowing, easing the environment temperature effects on the wastewater temperature.

The pH and temperature values are within the limits established by Brazilian resolution on discharge standards for domestic wastewater (Resolution CONAMA 430), whose pH values stipulates between 5 and 9 and temperature lower than 40°C.

3.2 DO

An increase in DO concentration was observed after the treatment of wastewater in the duckweed pond (Figure 4). In some instances, the DO concentrations at the entrance reached null values and after the treatment with duckweeds, these values increased. On average, the increase in DO concentration was 1.73 mg.L^{-1}. The highest DO concentration at the entrance was 5.4 mg.L^{-1} and 6.2 mg.L^{-1} at the exit.

The Resolution CONAMA 430 does not set limits for the DO, should be maintained at water quality in the receiving body is classified, requiring a depuration study.

Mohedano (2010), using the same specie (*Landoltia punctata*) for the pig farming effluent treatment, also observed an increase in DO concentrations in the duckweed pond. The results showed that the effluent went from an anaerobic to an aerobic condition, reaching average value of 3.0 ± 1.2 mg.L^{-1} in the last pond of the adopted system.

Using the specie *Spirodela polyrrhiza* in synthetic domestic wastewater, Caicedo (2005) observed low oxygen concentrations. Tavares (2008) also found low DO concentrations (under 1.0 mg.L^{-1}) in pilot experiment, using four tanks each with a superficial area of 2.57 m^2 of and useful volume 3.8 m^3, observing a low relation superficial area/volume. On the work made by Caicedo (2005), this relation is even lower (1.44).

In this work, the relation superficial area/volume was 3.38, showing that the highest DO concentrations may be associated with this higher relation; therefore, the larger the superficial area and the shallower the tank, the more efficient the process of gas diffusion will be.

At the same time as the photosynthetic activity favors the oxygenation, the vegetable covering reduces the atmosphere contact surface, reducing the oxygen diffusion, which has been a disagreement point among authors about the presence of DO in a duckweed pond (Al-Nozaily *et al.*, 2000; Körner *et al.*, 1998).

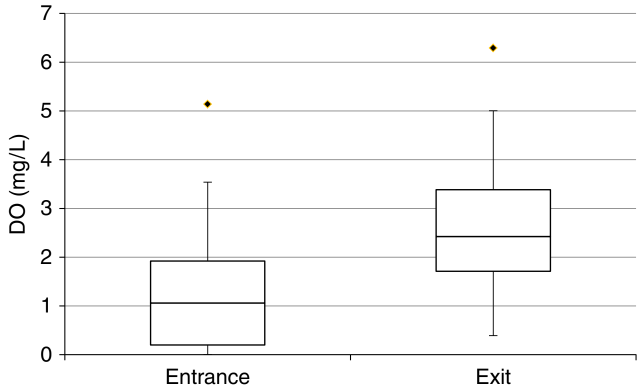

Figure 4. Distribution of DO concentrations in the duckweeds pond

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According to Mohedano *et al.* (2014), most duckweeds species, such as the *Landoltia punctata*, have upturned stomata that release oxygen in the atmosphere, which does not help to explain the DO increase in the water column. As a hypothesis, these authors believe that the thin cellular wall, the low lignin content and the chloroplast present on the duckweed roots allow the oxygen flow from the vegetable tissues to the water through direct diffusion, benefiting the heterotrophic community adhered in the roots by DO use and reinforcing the organic matter oxidation in the pond.

3.3 Efficiency evaluation of COD and BOD_5 removal

The COD concentration at the duckweed pond entrance varied during the experimental period. These variations may have occurred because it is a real WWTP effluent, which presented floating on the evaluated variable concentrations. The highest superficial load applied was 440.5 kg.ha-1.day^{-1} and the mean value was 262.74 kg.ha-1.day^{-1} of COD, which was higher than the load presented by Mohedano *et al.* (2014). These researches applied a load of about 131 kg.ha-1.day^{-1} of COD reaching an average removal efficiency of 96.7 percent.

While evaluating the COD concentration at the entrance of the pond, the highest value found was 547 mg.L^{-1} and the lowest was 34 mg.L^{-1}(Figure 5). In the period with the highest concentration, the removal efficiency was of 30.35 percent and for the lowest concentration, the removal efficiency was of 50.0 percent.

Körner *et al.* (1998) reached COD removals from 74 to 78 percent with retention time of three days, using domestic wastewater; however, the authors kept the duckweeds under constant temperature and light conditions, which were not adopted in the current study.

Tavares *et al.* (2008) also obtained good performance with the macrophyte *Lemna valdiviana* on the pig farming effluent tertiary treatment, evaluating five different COD contents (400, 550, 700, 850, and 1,000 mg.L^{-1}). The 400 and 550 mg.L^{-1} COD contents had the best removal efficiency (94.8 and 92.7 percent, respectively) with HRT of 21 days. It is possible to notice that, with longer HRT, the COD removal efficiency was more satisfactory, which can explain the low removal efficiencies found in this work when the HRT was 3.8 days.

For BOD_5, the highest removal efficiency was 92.32 percent (Figure 6) and it occurred in an initial concentration of 128.0 mg.L^{-1}, getting to 10 mg.L^{-1} after the duckweeds treatment. It is possible to notice that for the lowest BOD_5 concentrations at the duckweed pond entrance there were higher removal efficiencies.

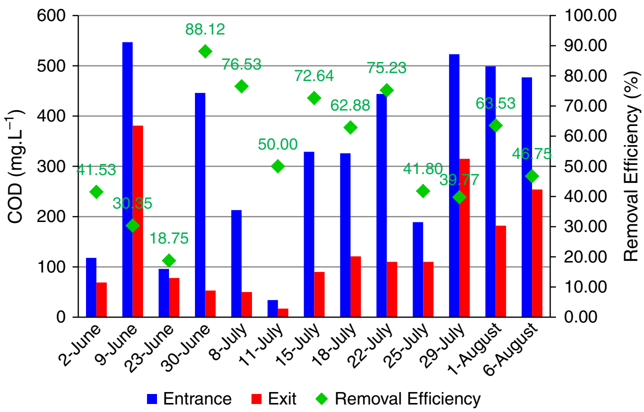

Figure 5.
COD (mg.L^{-1}) concentration and removal efficiency (percent)

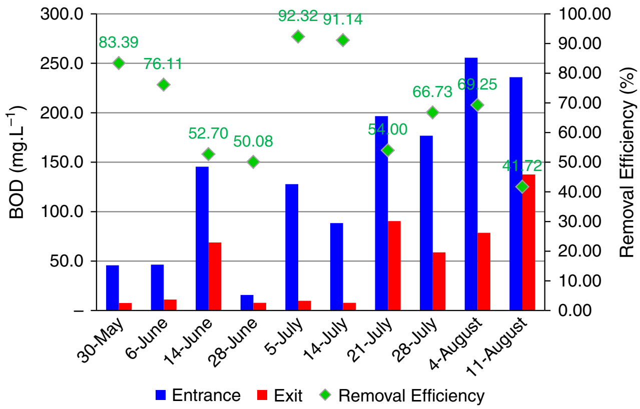

Figure 6.
BOD_5 ($mg.L^{-1}$) concentration and removal efficiency (percent)

The experiments developed by Alaerts *et al.* (1996) found that with an HRT of about 20 days, the water column remained aerobic during the entire period, which made it possible to obtain BOD_5 removals of 96 percent from domestic effluent in a duckweed pond.

Iqbal (1999) reports that the duckweed roots retain organic particles and these particles are subjected to aerobic microorganisms biodegradation and part of the degraded products are absorbed by the plants. The regions that are closer to the roots present higher DO concentration, which stimulates the aerobic organic matter oxidation, and therefore, the BOD_5 reduction. The excessive removal of plants and the HRT reduction can impair the organic matter removal efficiency.

In general, the BOD_5 removal efficiency was higher than the COD. It is important to highlight that the stabilization pond effluent has a great amount of microalgae, which may not have been degraded under the duckweed shadowing in only 3.8 days of HRT.

3.4 Evaluation of TN and TP removal efficiency

Figure 7 presents TN concentrations and removal efficiency during the experimental period. It is possible to observe a TN peak of 500.0 $mg.L^{-1}$ at the duckweed pond entrance; after this peak, the concentration values reduced considerably. The highest removal efficiency found was 72.67 percent (150 $mg.L^{-1}$ at the entrance and 38 $mg.L^{-1}$ at the exit). The lowest removal efficiency was 16.13 percent (62 $mg.L^{-1}$ at the entrance and 52 $mg.L^{-1}$ at the exit).

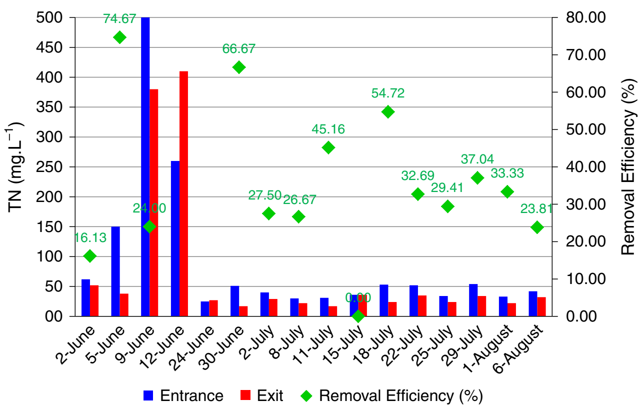

Figure 7.
TN concentration ($mg.L^{-1}$) and removal efficiency (percent)

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It was also observed that in two collects the TN concentration was higher at the exit in relation to the entrance. It can be explained by the fact that the collect was made on the same day that the WWTP effluent was put into the storage tank, this way the wastewater at the exit of the pond was not the same wastewater at the entrance.

Mohedano *et al.* (2012) obtained a 98.3 percent efficiency in the Total Kjeldahl nitrogen removal in the pig farming effluent treatment, using the specie of this research; however, they used 136 days of HRT. The authors state that the superficial application rate is important data for comparison with other studies. This way, the rate applied by the authors was 46 kg.ha-1.day^{-1}. The highest superficial rate applied to this study was 402.7 kg.ha-1.day^{-1} of TN, which was really higher than the one applied by the authors. The lowest rate applied was 20.1 kg.ha-1.day^{-1} of TN.

Figure 8 shows the TP concentration and removal efficiency throughout the monitoring period.

A peak of 102 mg.L^{-1} of TP concentration was observed at the entrance of the duckweed pond, which was reduced to 34.5 mg.L^{-1} (removal efficiency of 66.18 percent). After this peak, there was a significant reduction of TP concentrations at the entrance of the duckweed pond. The lowest concentration was 7.4 mg.L^{-1} at the entrance, reducing to 4.9 mg.L^{-1} after the treatment with duckweeds, with a removal efficiency of 33.78 percent; however, the lowest removal efficiency found was 14.29 percent (11.9 mg.L^{-1} at the entrance and 10.2 mg.L^{-1} at the exit).

El-Shafai *et al.* (2007) reported a phosphorus removal of 78 percent in domestic wastewater with HRT of 15 days, using *Lemna gibba* and *Lemna minor*; however, in winter, the phosphorus removal was reduced to 40 percent. Körner *et al.* (1998) showed phosphorus reduction from 63 to 99 percent with HRT of three days, in a domestic wastewater treatment.

Mohedano *et al.* (2012) obtained 94.5 percent of TP removal efficiency, using the *Landoltia punctata* specie, in a pig farming effluent treatment, with 136 days of HRT, applying a rate of 3.9 kg.ha-1.day^{-1} of TP, being removed 3.6 kg.ha-1.day^{-1} from the duckweed ponds in series.

Xu and Shen (2011) also found good phosphorus reduction, 89.4 percent, using the specie *Spirodela oligorrhiza*, in the diluted pig farming effluent treatment. These research works obtained a reduction from 21.4 to 32.4 percent after the first week and from 24.0 to 53.2 percent after the second week of experiment.

The absorption of nitrogen, phosphorus and potassium, among many other nutrients, is critical to the metabolism of all higher plants. The values for phosphorus removal by duckweeds found in the literature are 5-10 times lower than for nitrogen removal.

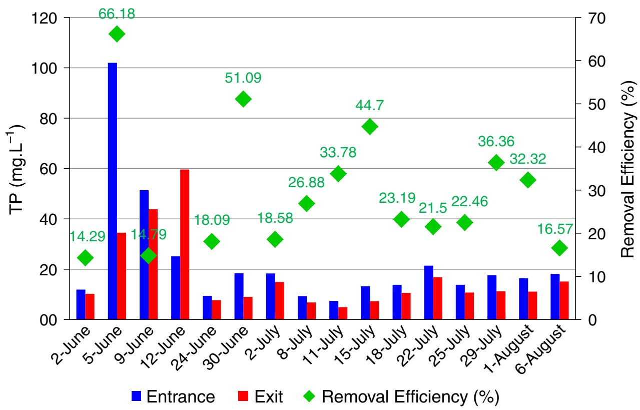

Figure 8.
TP concentration (mg.L^{-1}) and removal efficiency (percent)

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Phosphorus is removed through assimilation by plants, sedimentation and adsorption. According to Iqbal (1999), the ability to uptake by plants depends on the frequency of harvest, growth rate and availability of phosphorus in the form of orthophosphate.

Table I presents the average concentration values and standard deviation for BOD, COD, TN and TP.

The high concentration values found at the entrance of the duckweed pond, similar to raw sewage, may indicate that the sewage brought to the laboratory did not come from the stabilization pond output. We cannot say that the stabilization pond is not having an adequate treatment efficiency. Probably, other possible reason for this is that some sludge may have been suctioned with the effluent. The low efficiency is due the high load and low HRT.

3.5 TS removal efficiency evaluation

In general, the TS concentrations did not present great variations at the duckweed pond entrance; however, a peak of 956.0 mg.L^{-1} was observed, reaching a removal efficiency of 20.71 percent (Figure 9). This peak coincides with high concentrations of other variables, for example, the BOD_5 and COD, because the experiment was made with real effluent.

The lowest TS concentration at the entrance was 312.0 mg.L^{-1}, reaching 260.0 mg.L^{-1} at the exit. The highest removal efficiency found was 48.9 percent (548.0 mg.L^{-1} at the entrance and 280.0 mg.L^{-1} at the exit).

Skillicorn *et al.* (1993) and Iqbal (1999) report that the main mechanisms for solid reduction in ponds with duckweeds are physical filtering through the roots, wind blocking, which makes a proper sedimentation environment and, especially, the algae reduction through the shadowing.

Tavares *et al.* (2008), using duckweeds in the tertiary pig farming treatment, obtained a TS removal efficiency of 77 percent when the COD concentration was 400 mg.L^{-1}, in a 21-day HRT. Polisel (2005) found low TS removal efficiency (4.1 percent) using a two-day HRT. Therefore, it is possible to affirm that HRT is an important variable in TS removal.

	BOD		COD		TN		TP	
	Entrance	Exit	Entrance	Exit	Entrance	Exit	Entrance	Exit
Average	133.44	47.90	326.23	140.77	83.43	54.43	22.83	14.31
SD	83.40	45.90	178.34	110.98	123.63	94.18	24.19	10.74

Table I. Average concentration values and standard deviation (SD), mg/L

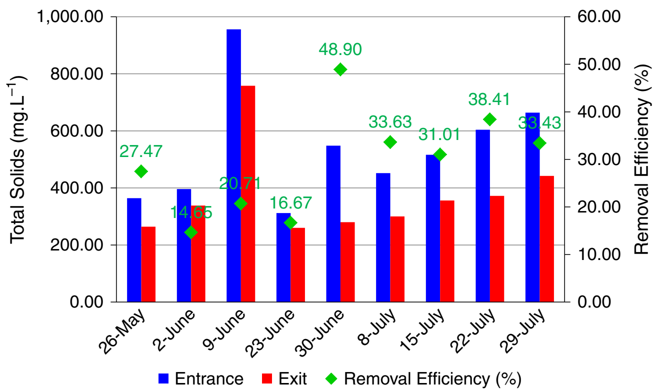

Figure 9. TS concentration (mg.L^{-1}) and removal efficiency (percent)

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3.6 Quantitative biomass evaluation

The weight gain values and RGR obtained from the collects made throughout the experiment are presented in Table II. The RGR values ranged between 3.6 and 10.3 $g.m^{-2}.day^{-1}$.

The occurrence of negative weight gain values is observed in two collects, which can be explained by the variation in effluent composition from the WWTP. As it can be observed, some variable concentrations (COD, TN, TP and TS) increased in some instances during the experimental period. These higher concentrations may have affected the plants growth.

The quantity and frequency of duckweed collects play an important role on the treatment effectiveness and on the nutritional value of plants. Regular collects ensure that the nutrients and toxins are permanently removed from the system. Because the younger plants present a better nutrient profile and higher growing rates than the older plants, the regular collect is important to maintain a healthy and productive culture.

Mohedano *et al.* (2012) obtained an average RGR of 18 $g.m^{-2}.day^{-1}$ of dry duckweeds (*Landoltia punctata*) in the Pond 1 and 8.3 $g.m^{-2}.day^{-1}$ in the Pond 2, pointing that rate differences between the ponds is due to the nutrient different loads, higher in Pond 1.

The collect frequency used by these authors was varied according to the biomass production, which may be affected by many factors, such as temperature, biomass density, photoperiod, toxic compounds and nutrients availability.

Using the same species of this research and with two-day collect frequency in synthetic pig farming effluent, Cheng *et al.* (2002) obtained an RGR of 32 $g.m^{-2}.day^{-1}$. Aiming better knowledge in the relation between the nutrient absorption rate and the duckweeds RGR, the authors tested different dilutions of nitrogen and phosphorus (NH_4-N and PO_4-P) in constant temperature, obtaining the best absorption rates and growing in the initial concentrations 240 $mg.L^{-1}$ of NH_4-N and 31.0 $mg.L^{-1}$ of PO_4-P. The controlled conditions for duckweed cultivation can explain the higher production rates in relation to this study.

Tavares (2008) obtained average production rate of 10.5 $g.m^{-2}.day^{-1}$ of dry matter, using the species *Lemna valdiviana*, weekly collected, in the pig farming effluent treatment. The author concluded that the biomass production was influenced by temperature, since lower values were observed in the colder months.

Körner and Vermaat (1998) report that high organic matter concentrations are harmful to the duckweeds growing due to the formation of a biofilm on the roots, impairing the nutrients absorption and these plants growing. The duckweeds become yellowish, agglomerated and they do not grow, what reinforces the hypothesis that an effluent with high organic matter concentrations has a toxic effect on them. This fact was also observed by Tavares (2008), that the lowest biomass production occurred in the test with initial COD of 1,000 mg/L, indicating that the COD high concentration may have played a toxic role.

There are limiting factors that are unanimous among the researchers: species used, temperature, light, nutrients availability, toxic compounds presence and the population density itself. Therefore, it is important to mention that the biomass

Collects dates	Collected biomass (*g*)	Weight gain (*g*)	RGR ($g.m^{-2}.day^{-1}$)
28-May	2.549	0.939	9.104
04-June	1.940	0.330	6.929
11-June	1.481	−0.129	−5.289
18-June	1.012	−0.598	−3.614
02-July	2.468	0.858	8.814
09-July	2.460	0.436	8.786
16-July	2.739	1.129	9.782
23-July	2.891	1.281	10.325
30-July	2.285	0.675	8.161

Table II. Biomass produced in the duckweed pond, from the dry mass productivity comparisons were made with different duckweeds species, with distinct effluents and diverse operational characteristics, what certainly contributed to the differences in biomass productivity.

4. Conclusions and recommendations

According to the objectives and results obtained throughout this study, some statements can be made:

- There were positive results in pollutant removal in the duckweed ponds, being an efficient technology with operational simplicity for the domestic effluent polishing. The highest removal efficiencies found were 88.12 percent for COD, 92.32 percent for BOD, 74.67 percent for TN and 66.18 percent for TP.
- It is believed that the duckweed pond performance was not compromised by the environmental conditions registered during the experimental period. The plants survive between 10.5°C and 34.5°C.
- The highest production rate was $10.325\ g \cdot m^2 \cdot day^{-1}$.
- There were ranges on the duckweed density and RGR, what can be associated with the high concentrations of some variables, such as organic matter, TN and TP on the stabilization pond effluent.

This way, it is recommended that the effluent composition is evaluated on what refers to the concentration of variables that will be analyzed in the duckweeds treatment, so that the effluents that will be treated have lower concentrations than the ones used in this work.

It is also possible to verify the behavior of other variables, such as the nitrogen (nitrate, nitrite, ammonia), making possible the calculation of nitrogen balance in duckweed ponds. The Chlorophyll-a analysis may also be suggested because it indirectly points the algae presence in the system, making possible better explanations about BOD_5 removal efficiency, TS and nutrients.

A qualitative analysis of duckweeds, for example, analysis of nutrients, protein and starch is one of the great interests for ethanol production. Therefore, analyses of this compound would be really important.

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