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Constructed wetland in wastewater treatment

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ABSTRACT. Physical and chemical variables of soil and water were measured to determine the effectiveness of a constructed wetland for wastewater treatment. Eight different macrophyte species, namely *Eichhornia crassipes*, *Alternanthera philoxerodos, Heteranthera reniformis, Hydrocotyle umbeliferae, Ludwigia elegan, Ludwigia sericea*, *Myriophyllum aquaticum* and *Thypha domingensis*, were transplanted. Inlet water and outlet water were the two sampling sites evaluated. There were significant differences ($p < 0.05$) when limnological characteristics between inlet and outlet water from the constructed wetland were compared. In general, dissolved oxygen was over 4 mg L^{-1}, and conductivity was high, above 80 $\mu S\ cm^{-1}$. Chlorophyll-*a* levels generally tended to decrease at the wetland outlet and were higher during the rainy period (fish growth period). Results show that ammonia, total phosphorus, BOD_5, phosphorus and organic matter in the sediment removals in the constructed wetland were higher, indicating that macrophytes played an important role in removing these variables. The use of constructed wetland is a viable technology for the biological treatment in aquaculture and swine wastewater.

Key words: effluent, wastewater, physical and chemical parameters, macrophyte.

RESUMO. Uso de "wetland" construído para tratamento de resíduos. Variáveis físico-químicas da água e do solo foram avaliadas a fim de verificar a eficiência de um "wetland" construído no tratamento de resíduos. Foram escolhidas oito espécies de macrófitas baseadas na capacidade de retenção e disponibilidade no local de estudo. Dentre elas estão: *Eichhornia crassipes*, *Alternanthera philoxerodos, Heteranthera reniformis, Hydrocotyle umbeliferae, Ludwigia elegan, Ludwigia sericea*, *Myriophyllum aquaticum* e *Thypha domingensis*. Foram amostrados dois pontos um na entrada e outro na saída de água do "wetland". Diferenças significativas ($p < 0,05$) foram observadas entre a entrada e saída do "wetland" em relação às variáveis limnológicas. Em geral, foram observadas concentrações de oxigênio dissolvido acima de 4 mg L^{-1} e de condutividade, acima de 80 $\mu S\ cm^{-1}$. As concentrações de clorofila-*a* decresceram ao passar pelo "wetland", sendo mais elevadas no período de chuva (período de engorda de peixe). Amônia, fósforo total, DBO_5, fósforo e matéria orgânica do sedimento decresceram ao passar pelo "wetland" construído para indicar a eficiência desse sistema. Assim, essa tecnologia biológica (macrófitas aquáticas) apresenta-se como uma opção adequada para melhoria de efluentes de aquicultura e de suinocultura.

Palavras-chave: efluente, resíduos, variáveis físico-químicas, macrófita.

Introduction

Natural treatment systems, including constructed wetlands (CWs), have been extensively used in aquaculture due to the fact that aquatic plants, as primary producers, retrieve from the water the nutrients and other substances needed for their development. In addition, macrophytes are surrounded by several and diverse communities of microorganisms, such as phytoplankton, zooplankton, bacteria, fungi, invertebrates and others, which also recover material from the water for their own metabolism. Constructed wetlands are significantly important because they require low capital, operating costs and versatile removal mechanisms when compared to other effluent treatment systems (Sipaúba-Tavares *et al.,* 2002).

In current research, CW may be defined as "any setup that has been realized by human interface in order to treat wastewater and that is inhabited by plants" (Makerere University…, 1997).

Developing countries usually consider CWs to be one of the most promising technologies in wastewater treatment due to their low costs, simple operation and maintenance, low secondary pollution and agreeable environmental aspects (Chen *et al.,* 2008).

Constructed wetlands are an option for nitrogen removal from wastewater treatment plants and are highly acceptable as cleansing systems connected to ordinary wastewater treatment plants with insufficient biological treatment (Wöirman and Kronnäs, 2005). Wastewater treatment in aquatic macrophyte systems occurs through several mechanisms, which include solid settling, plant uptake of contaminants, biotransformation, and physical and chemical reactions (Sooknah and Wilkie, 2004).

Many factors may affect CW behavior: climate, type of vegetation, effects of the local environment, operating strategies etc. Among these factors, the type of macrophyte and loading rate are the only items controlled by the designer (Jing *et al.,* 2002).

When compared to conventional treatment systems, CW technology is cheaper, easily operated and more efficient to maintain. It is well known that photosynthetically macrophyte-generated oxygen has an important role in the biodegradation of organic matter of wastewater by aerobic and facultative bacteria (Saha and Jana, 2003). Since aquatic plants have a natural mechanism for pumping air via their root system, the root area provides an oxygen-rich environment which supports a range of aerobic bacteria similar to those found in other sewage treatment processes (Mashauri *et al*., 2000).

Information on the effect of CW in aquaculture and swine effluents is important and necessary, and would substantially induce further research because of the production of improved water quality at the effluent that would meet discharge criteria. The present study evaluates the physical and chemical parameters of a CW by assessing its effectiveness in aquaculture and swine wastewater.

Material and methods

The present study was undertaken at the Universidade Estadual Paulista (Unesp) in Jaboticabal, São Paulo State, Brazil (21º15'S; 48º18'W) in a CW at an aquaculture effluent that received water from six large ponds, whose areas varied between 2,000 and 9,000 m^2. Some of these ponds receive water from other small ponds and from the frog and shrimp cultures. The CW has two other water entrances: one originates from swine wastewater treated by Upflow Anaerobic Sludge Blanket (UASB), whose matter is discharged when reactors are switched on; the other originates from rain water discharged from the upper layers of the University premises, in great volume between November and January (Figure 1).

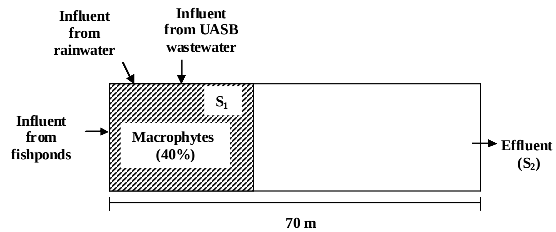

Figure 1. Layout of the constructed wetland system for the treatment of fishpond water, rainwater and UASB wastewater, where: S_1 and S_2 = sampling sites.

The CW measures 70 x 1 x 0.30 m. The system was provided with eight types of macrophytes, while planting density of vegetation for emergent plants was 5 plants m^{-2} and for floating plants 20% of surface coverage. Coverage comprised 40% of the CW's total area. Floating species *Eichhornia crassipes* was chosen due to its high uptake rates investigated in a previous study (Sipaúba-Tavares *et al*., 2002). *Alternanthera philoxerodos, Heteranthera reniformis, Hydrocotyle umbeliferae, Ludwigia elegan, Ludwigia sericea*, *Myriophyllum aquaticum* and *Thypha domingensis* were chosen because they are very common in the region. Immediately after plant transplantation, the CW, characterized by a shallow and muddy bottom, was filled to a depth of approximately 0.30 m with a continuous water flow through the CW. Two sampling sites were evaluated: S_1 = inlet water from fishpond, UASB wastewater and rain water influent; S_2 = wetland outlet. Evaluations occurred roughly biweekly, throughout 2003 and 2004.

Conductivity, temperature, pH and dissolved oxygen were assessed with a Horiba U10water quality checker. Ammonia, nitrite, nitrate, total phosphorus and orthophosphate were determined following techniques by Golterman *et al*. (1978) and Koroleff (1976). Hardness, 5-day biochemical oxygen demand (BOD_5), total dissolved solids (TDS) and total suspended solids (TSS) were measured according to Boyd and Tucker (1992). Chlorophyll-*a* was determined according to Nush (1980). Total sediment phosphorus and organic matter concentrations were also calculated. Sediment samples were collected using a 4-cm diameter PVC core at sites S_1 and S_2, according to Andersen (1976). All samples were carried to the laboratory in cold boxes.

Yearly limnological characteristics were analyzed at two sites to verify whether there was any difference between the CW's inlet (S_1) and outlet (S_2) water. Mann-Whitney's non-parametric test was used with n_2 between 9 and 20, applying the bimodal test and $p = 0.05$.

Results and discussion

Significant differences ($p < 0.05$) existed when limnological characteristics between inlet and outlet water from the CW were compared (Table 1). Site S_1, which receives water from fishponds and rainwater, coupled with UASB-treated swine wastewater, also contributed a great load of matter in the CW. Due to load from UASB treated swine wastewater during the year, an increase in some variables, such as conductivity, hardness, nitrate, orthophosphate, and TDS may have also probably occurred during the experiment (Table 1, Figure 2).

Table 1. Results of the analysis of water limnological parameters at sites S_1 and S_2, where: U = Mann-Whitney test; ⋆ = significance ($p < 0.05$).

Parameters	S_1	S_2	U
Temperature	24.5	23.5	53⋆
Hardness	30.5	31.8	58⋆
pH	6.4	6.9	66⋆
Dissolved Oxygen	5.9	5.3	61⋆
TSS	19.4	14.0	43⋆
TDS	57.4	76.6	70⋆
Conductivity	102.6	104.6	63⋆
BOD_5	3.9	3.7	62⋆
Chlorophyll-*a*	70.8	62.2	55⋆
Ammonia	146.5	65.5	53⋆
Nitrite	9.3	8.5	71⋆
Nitrate	241.5	300.0	58⋆
Orthophosphate	49.5	57.3	33⋆
Total phosphorus	90.9	72.5	46⋆

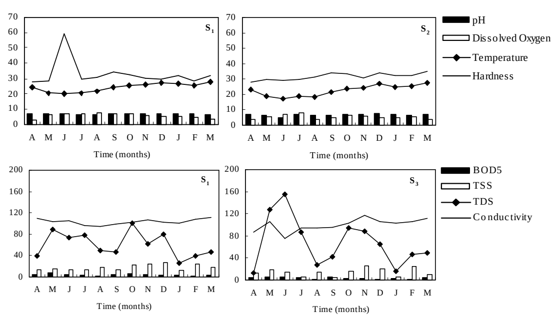

Figure 2. Average variation of temperature (°C), hardness (mg L^{-1}), pH and dissolved oxygen (mg L^{-1}), 5-day biochemical oxygen demand (BOD_5 – mg L^{-1}), total suspended solids (TSS – mg L^{-1}), total dissolved solids (TDS – mg L^{-1}), and conductivity (μS cm^{-1}) at the CW sites (S_1, and S_2) during the experiment.

Except for nitrate and nitrite, the decrease in nutrients was higher than 80%. Due to water movement, the nitrite rate was high at site S_2 when compared to that in inlet water (S_1) (Table 2). With regard to nitrate, it is accepted that both nitrate and organic matter concentrations may limit the nitrate removal rate of a biological denitrification process. Although CW denitrification processes involve a great amount of complexities, the sedimentation may be still the essential factor limiting denitrification and nitrate removal in CWs.

Table 2. Water nutrients, chlorophyll-*a*, total phosphorus (Total-P) and organic matter (OM) concentrations of sediment at sampling sites (S_1 = inlet water and S_2 = outlet water) and mean decrease in CW percentages.

Parameters	S_2		S_3		Decrease
	Mean	Range	Mean	Range	(%)
Nitrite (μg L^{-1})	14	0.7-44	17	0.9-62	-
Nitrate (μg L^{-1})	217	13-431	234	7-388	-
Ammonia (μg L^{-1})	162	11-375	129	8-409	80
Total Phosphorus (μg L^{-1})	84	0.3-179	73	8-138	87
Orthophosphate (μg L^{-1})	28	10-59	38	7-116	-
Chlorophyll-*a* (μg L^{-1})	76	26-133	66	37-137	87
TSS (mg L^{-1})	28.5	7-135	14.5	4-26	51
BOD_5 (mg L^{-1})	4.3	1.6-8.2	3.6	1.9-5.3	84
Dissolved Oxygen (mg L^{-1})	5.6	2.3-9.0	5.0	3.6-8.1	89
Sediment Total-P (mg L^{-1})	0.26	0.1-0.4	0.23	0.1-0.4	88
Sediment OM (%)	15	11-23	13	11-16	87

Since oxygenation in the rhizosphere is not sufficient for complete nitrification, nitrogen removal is limited. Oxygen, commonly considered the inhibitor to the impact denitrification rate, is a master regulator of the synthesis and activity of reductive enzymes in the bacterial denitrification pathway (Ma *et al*., 2008). Nitrification is inhibited at low dissolved oxygen concentrations, leading towards incomplete nitrification coupled with an increased nitrite concentration in the effluent (S_2).

Insufficient detention time in the occurrence of denitrification also affected the removal rate of nitrate. In fact, short residence time does not permit complex sedimentation of organic material, and most of the nitrogen is mainly supplied in dissolved form (Søvik and Mørkved, 2008).

Whereas residence time in the CW averaged 38.6 days during the dry period (June to August), it amounted to 6.5 days during the rainy period (November to March). Water currents in the CW caused water oxygenation during the period, with highest concentrations in inlet water (S_1). This fact revealed plant metabolism in the water quality of the CW.

Oxygen decrease at the CW outlet may be explained by the fact that when the sediment is flooded, the oxygen present will be promptly consumed by microbial respiration and chemical oxidation. Dissolved oxygen contents from influent to effluent, albeit on the decrease, were usually higher than 2.3 mg L^{-1}. These results imply that the CW provided an aerobic condition, which probably hindered denitrification from occurring in the water column.

Nitrification and denitrification, which depend on different dissolved oxygen concentration environments, are considered to be the most important processes in about 90% of the nitrogen removed. In most conventional CWs, the limitation of nitrogen removal is the lack of sufficient nitrification due to the shortage of dissolved oxygen in the wastewater (Chen *et al.,* 2008).

Ammonia decrease has been reported and total phosphorus in the wetland outlet (S_2) is a good indicator of the system's positive effect, since ammonia is considered to be an eutrophication-causing polluting agent common to intense agricultural regions (Tables 1 and 2). Removal of nitrogen in a CW system depends on a combination of the settlement of particulate matter, their uptake into plants and bacterial biomass, and bacterial nitrification and de-nitrification. Blankenberg *et al.* (2008) found low nitrogen retention (< 2%) in the period with leakage of nitrogen after large runoff episodes.

The removal of nitrogen and phosphorus are crucial issues for most CWs. Phosphorus is primarily removed by cation exchange reactions with the substrate. However, plants may retain 10-50% of nutrients, most of which are absorbed during their intensive growth period. In the case of the CW under analysis, total phosphorus was mechanically sieved from the effluent (removal = 89%). However, orthophosphate significantly increased by 73.7%, since removal of total phosphorus is primarily related to the retention capacity of root and to equilibrium of phosphorus concentration by anaerobic conditions (Lee *et al*., 2004) (Table 2).

Total phosphorus was stored mainly in the sediment compartment, characterized by comparatively small amounts in the water column (Table 2). Hadad *et al*. (2006) reported that total phosphorus in the sediment doubles its initial concentration owing to co-precipitated phosphorus with high pH rates and to calcium and carbonate concentrations in the incoming wastewater together with calcium carbonate in the influent. No variance in organic matter in the sediment was reported, except in September (0.23%), when it was associated with UASB discharge (Table 2).

Sediments in CWs are of great importance to living organisms and provide storage for many nutrients. Their permeability affects the wastewater flow through the CW in which chemical and biological transformations by microorganisms and plants occur (Calheiros *et al.,* 2007).

In general, a TDS decrease occurred in the CW, markedly in April, August and January in the outlets respectively with 13.5, 17.0 and 16.2 mg L^{-1}. Highest concentrations at site S_2 were observed in May (117 mg L^{-1}) and June (155 mg L^{-1}), which coincided with the post-fish-growth period and the start of the dry period, respectively. Highest concentrations of TDS and TSS were reported at site S_1 during the rainy period (Figure 2). Since they provide a suitable habitat for many decomposing microorganisms in the rhizosphere, macrophytes play an indirect but important role in the decrease of suspended solids, nutrients and organic matter from various types of wastewater (Ciria *et al*., 2005).

BOD_5 decrease in CW is primarily achieved by aerobic and anaerobic degrading activities, brought about by various bacteria. Aerobic and anaerobic degradation intensity is highly dependent on the oxygen contents in the wastewater flowing through the CW system (Chen *et al*., 2008). The present study revealed that removal amounted to 84%, associated with decreasing chlorophyll-*a* concentration in the water (Figure 2; Table 2).

The CW was efficient in TSS removal (51%), especially during the dry period, when low current velocity in the CW served as a natural sedimentation area that usually eliminated high TSS concentrations (Figure 2).

Particulate matter constitutes a significant fraction of organic material entering the wastewater treatment plants, and the removal processes reduces not only overall amount of organic matter but also modify the chemical composition of the remaining organic material (Calheiros *et al*., 2007).

Temperature is typically a critical factor affecting the wetland's performance in removing the major pollutants of interest (Lin *et al.,* 2007). Water temperatures ranged from 16.2 to 27.8°C. At site S_2 (outlet), between November to January (rainy period), pH was alkaline and varied between 7.0 and 7.5. However, in the inlet water, pH was acidic and varied between 5.8 and 6.9 (Figure 2). Aquatic plants may obtain inorganic nutrients from the water column, displaying an inverse relationship with pH, or rather, an increase in pH and a decrease in plant density in the medium (Forchhammer, 1999).

Water hardness concentrations ranged between 26.0 and 33.8 mg L^{-1}, with a slight rise in September. Conductivity was low during the dry period, although at site S_1, due to received UASB-treated swine wastewater and rain water, it was above 100 $\mu S\ cm^{-1}$ (Figure 2). Conductivity varied between 80 and 118 $\mu S\ cm^{-1}$, which is lower than the toxicity level (404 $\mu S\ cm^{-1}$) for the growth of aquatic plants (Sooknah and Wilkie, 2004). In the case of the aquatic plants used in this study, the pond water from which the plants originated had an average conductivity of 50 $\mu S\ cm^{-1}$.

The importance of CW implementation in fish farm effluents in Brazil is due to the fact that most fish farmers discharge the water directly into natural streams and rivers. Specific laws on treatment of effluents in Brazil are either very inefficient or not applied. This is extremely serious when one takes into account the recent fast growth rate in fish farming in Brazil. Needless to say, the above-mentioned process needs technologies that can effectively reduce the negative impact of fish farming on the environment.

Results show that ammonia, total phosphorus, BOD_5, phosphorus and organic matter in the sediment removals in the CW were higher and indicated that macrophytes had an important role in removing these variables. Removal efficiencies are believed to be higher after a few years of operation when the system becomes mature. Therefore, CW is expected to have a better performance in the future. In fact, CW may be used to upgrade the quality of aquaculture effluent and other effluents to acceptable levels. A detailed study is needed to reevaluate this particular CW with regard to choice of aquatic plants and retention time so that a more effective management of the CW as a regional model, with low costs and positive response to environment sustainability, may be determined.

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References

ANDERSEN, J.M. An ignition method for determination of total phosphorus in lake sediments. *Water Res.*, New York, v. 10, n. 4, p. 329-331, 1976.

BLANKENBERG, A.G.B. *et al*. Nitrogen retention in constructed wetland filters treating diffuse agriculture pollution. *Desalination,* Amsterdam, v. 226, n. 1-3, p. 114-120, 2008.

BOYD, C.E.; TUCKER, C.S. *Water quality and pond soil analyses for aquaculture*. 1. ed. Alabama: Auburn University Press, 1992.

CALHEIROS, C.S.C. *et al*. Constructed wetland systems vegetated with different plants applied to the treatment of tannery wastewater. *Water Res.*, New York, v. 41, n. 8, p. 1790-1798, 2007.

CHEN, Z.M. *et al*. A vertical subsurface-flow constructed wetland in Beijing. *Nonlinear Sci. Num. Sim.*, Oxford, v. 13, n. 1, p. 1986-1997, 2008.

CIRIA, M.P. *et al*. Role of macrophyte *Typha latifolia* in a constructed wetland for wastewater treatment and assessment of its potential as a biomass fuel. *Biosyst. Eng.*, London, v. 92, n. 4, p. 535-544, 2005.

FORCHHAMMER, N.C. Production potential of aquatic plant in system mixing floating and submerged macrophytes. *Freshw. Biol.*, Oxford, v. 41, n. 1, p. 183-191, 1999.

GOLTERMAN, H.L. *et al. Methods for physical & chemical analysis of fresh water*. 2. ed. Oxford: Blackwell Scientific Publication, 1978. (IBP handbook, 8).

HADAD, H.R. *et al*. Macrophyte growth in a pilot-scale constructed wetland for industrial wastewater treatment. *Chemosphere*, Oxford, v. 63, n. 10, p. 1744-1753, 2006.

JING, S.R. *et al.* Wetlands and aquatic processes: microcosm wetland for wastewater treatment with different hydraulic loading rates and macrophytes. *J. Environ. Qual.*, Madison, v. 31, n. 2, p. 690-696, 2002.

KOROLEFF, F. Determination of nutrient. *In:* GRASHOF, E. *et al.* (Org.). *Methods of seawater analysis*. German: Verlag Chemie Wenhein, 1976. p. 117-181.

LEE, C.Y *et al.* Performance of subsurface flow constructed wetland taking pretreated swine effluent under heavy loads. *Bioresour. Technol.*, Essex, v. 92, n. 2, p. 173-179, 2004.

LIN, Y.F. *et al*. Nitrate removal and denitrification affected by soil characteristics in nitrate treatment wetlands. *J. Environ. Sci. Health A*, Virginia, v. 42, n. 4, p. 471-479, 2007.

MA, W.K. *et al*. Relationship between nitrifier and denitrifier community composition and abundance in predicting nitrous oxide emissions from ephemeral wetland soils. *Soil Biol. Biochem.*, Elmsford, v. 40, n. 5, p. 1114-1123, 2008.

MAKERERE UNIVERSITY KAMPALA AND DEPARTMENT OF CIVIL ENGINEERING. *Constructed wetlands in East Africa, the Uganda chapter.* [S.l.]: Austria-East Africa Research Cooperation, 1997. (Phase one report).

MASHAURI, D.A. *et al.* Constructed wetland at the University of Dar es Salaam. *Water Res.*, New York, v. 34, n. 4, p. 1135-1144, 2000.

NUSH, E.A. Comparison of different methods for chlorophyll and phaeopigments determination. *Arch. Hydrobiol.*, Stuttgart, v. 14, p. 14-36, 1980.

SAHA, S.; JANA, B.B. Fish macrophyte association as a low-cost strategy for wastewater reclamation. *Ecol. Eng.*, Oxford, v. 21, n. 1, p. 21-41, 2003.

SIPAÚBA-TAVARES, L.H. *et al.* Utilization of macrophyte biofilter in effluent from aquaculture: I. Floating Plant. *Braz. J. Biol.*, São Carlos, v. 62, n. 4-A, p. 713-723, 2002.

SOOKNAH, R.D.; WILKIE, A.C. Nutrient removal by floating aquatic macrophytes cultured in anaerobically digested flushed dairy manure wastewater. *Ecol. Eng.*, Oxford, v. 22, n. 1, p. 27-42, 2004.

SØVIK, A.K.; MØRKVED, P.T. Use of stable nitrogen isotope fraction to estimate denitrification in small constricted wetland treating agricultural runoff. *Sci. Total Environ.*, Amsterdam, v. 392, p. 157-165, 2008.

WÖIRMAN, A.; KRONNÄS, V. Effect of pond shape and vegetation heterogeneity on flow and treatment performance of constructed wetlands. *J. Hydrobiol.*, Ujjain, v. 301, n. 1, p. 123-128, 2005.

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