CAFEi2016-18

Aquacultures effluent treatment in hybrid constructed wetland using *Eichhornia crassipes* and *Limnocharis flava*

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Abstract

Aquaculture has been recognized as one of important key economic areas in Malaysia's Economic Transformation Program. However, intensification with ineffective management, particularly of its effluent water, may pose additional threats to the greater environment. Constructed wetland is a promising and more eco-friendly and sustainable alternatives treatment method for the aquacultures effluent with low operational cost and low energy consumption. This study was conducted using two-stage Subsurface Flow (SSF)-Free Water Surface (FWS) systems of constructed wetland in treating catfish aquacultures effluent. The constructed wetlands were planted with water hyacinth (*Eichhornia crassipes*) for FWS and Yellow Sawah Lettuce (*Limnocharis flava*) for SSF Wetland. The performance of the SSF-FWS systems were determined by removal of organics, nutrients (nitrogenous compounds and phosphorus) and total suspended solid (TSS). The results show removal of Chemical Oxygen Demand (COD) (82.5%), Phosphorous (73.3 %), Nitrate (90.8%), Ammonia-nitrogen (99%) and TSS (98.1 %) at the end of experiments and concludes that SSF-FWS constructed wetland with *Eichhornia crassipes* and *Limnocharis flava* can improve the quality of the aquacultures effluent.

Keywords: aquacultures effluent, hybrid constructed wetland, *eichhornia crassipes*, *limnocharis flava*

INTRODUCTION

Effluent from aquaculture operations usually comprises four types of pollutants: solids discharged in the form of fish faeces and uneaten food, dissolved nutrients such as nitrogen and phosphorus resulted from fish metabolites, residuals from chemicals used in maintaining the culture water, treating diseases, and lastly release of living organisms (Jegatheesan et al., 2011). The high concentration of nutrients can cause imbalance ecosystems life in the water body where excess nitrate and phosphorus concentration can lead to eutrophication and hypertrophication of adjacent ecosystems, and harmful algae bloom formation thus reducing the suitability of aquatic life.

Despite the fact that there have been various technologies currently available, the use of constructed wetland is one of the more sustainable and eco-friendly alternatives to treat wastewater. Constructed wetland (CW) is manmade which has characteristics and capability like those of natural wetland. In Malaysia, as in Putrajaya, the CW systems have been utilized to treat nutrients runoff from upper catchment by relying on macrophytes and microorganisms in the water treatment process (Sim et al., 2008). CW systems are characterized by the advantages of moderate capital costs, low energy consumption and maintenance requirements and benefits of increased wildlife habitat (IWA, 2000). The treatment systems generally fall into one of two general categories which are Subsurface Flow Systems (SSF) and Free Water Surface Systems (FWS). SSF constructed wetlands are further divided into two flow regimes which are vertical flow (VF), and horizontal flow (HF) systems

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(Vymazal, 2010). Recently, the literature reported the hydrid CW where they combined various types of CW. Hybrid constructed wetlands are used primarily for enhanced the nitrogen removal and for treatment of various industrial and agricultural wastewaters. Hybrid CW can enhance the pollutant removal with advantages of various systems that complement each other (Vymazal, 2013).

The CW systems always show a great removal of contaminant such as organics, excessive nutrients, suspended solid and heavy/trace metals such as Cu, Cd, Hg, Pb, and Zn. The removal of contaminants in CWs is complex and depends on a variety of removal mechanisms, including sedimentation, filtration, precipitation, volatilization, adsorption, plant uptake, and various microbial and metabolic processes (Lim, 2002; Vymazal, 2007). Wetland vegetation (plant) is the most important component in a wetland system. Numerous studies have confirmed that water treatment is improved in vegetated systems compared to system containing no plants. The efficacy of these wetland plants was at its optimum when the vegetation was new and actively growing, absorbing abundant amounts of nutrients, minerals and waters as the plant transpired and produced large amount of biomass (Thullen et al., 2002).

Thus, the planted hydrid CW that combined both SSF and FWS CWs were used to treat the aquacultures effluent in order to reduce the concentration of organics, nutrients and total suspended solid thus improving the water quality.

MATERIALS AND METHODS

Experimental Setup

The experiment was carried out on a lab-scale hybrid stages constructed wetland (CW) that combines sub-surface flow (SSF) and free water surface flow (FWS) systems in series. The CW systems compared between planted CW and unplanted or control CW systems. This experiment follows methods of Lin *et al.*, (2005) but with different CW orientation. Each system consisted of four tanks: Influent tank, SSF tank, FWS tank and Effluent tank as in Figure 1. The CW systems were setup under a controlled environment structure to avoid contact with rainwater at the Institute of Sustainable Agrotechnology (INSAT), UniMAP, Perlis. The tanks for the SSF and FWS were 0.25 m in width, 0.4 m in length and 0.3 m in depth, with a total capacity of approximately 30 L. The flow of water in the CW systems was via gravity. Water hyacinth (*Eichhornia crassipes*) and Yellow Sawah Lettuce ((*Limnocharis flava)* were planted in FWS and SSF tank, respectively. The Hydraulic Retention Time (HRT) was set to 2 days and the experiment run in 2 weeks with replicate twice.

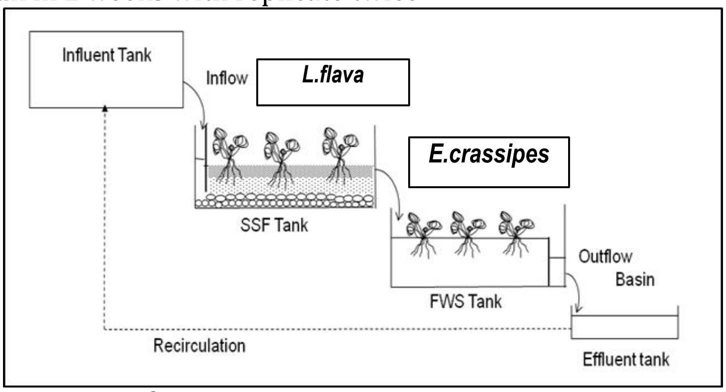


Figure 1. Experiment setup of SSF-FWS CW systems.

The aquacultures effluent water was collected from a commercial catfish pond near Timah Tasoh Lake. The water hyacinth (*Eichhorniac rassipes*) plants were collected from canal near Kangar while Yellow Sawah Lettuce (*Limnocharis flava)* plants were collected from paddy field near Uniciti, Padang Besar. These plants were selected due to their abundant availability in northern region of Malaysia and both plants have been demonstrated to have the ability to reduce pollutants and nutrients in wastewater. Both plants were collected 2 weeks prior experiment to assimilate the plants in the environment. The media or substrates used in the SSF CW were a mixture of gravels, coarse sand and soil at 1:2:2 ratios. All materials were cleaned from any debris by washing with tap water prior to putting into the SSF tank to avoid blockage of the wastewater flow through the media.

Sampling and Analysis

The aquacultural effluent water samples was analysed at the initial stage after sampling and were measured at the effluent tank every two days. All samples were analysed for Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), ammoniacal nitrogen (NH_3-N), Nitrate (NO_3-N) and Orthophosphate (PO_4-P). All tests were performed according to the Standard Methods (APHA, 2005). The COD and nutrients were analyzed using Spectrophotometer HACH DR2800, while TSS using oven drying procedure. Pollutant removal were analysed for their removal efficiency and removal performance. Pollutant removal performance of the FWS-SSF CW systems was developed using first-order plug flow kinetic model following Kadlec and Knight (1996). The higher the k value, the higher the performance of the treatment. The first-order plug flow kinetic model equation was as Equation (1):

$$C/C_o = e^{-kt} \quad (1)$$

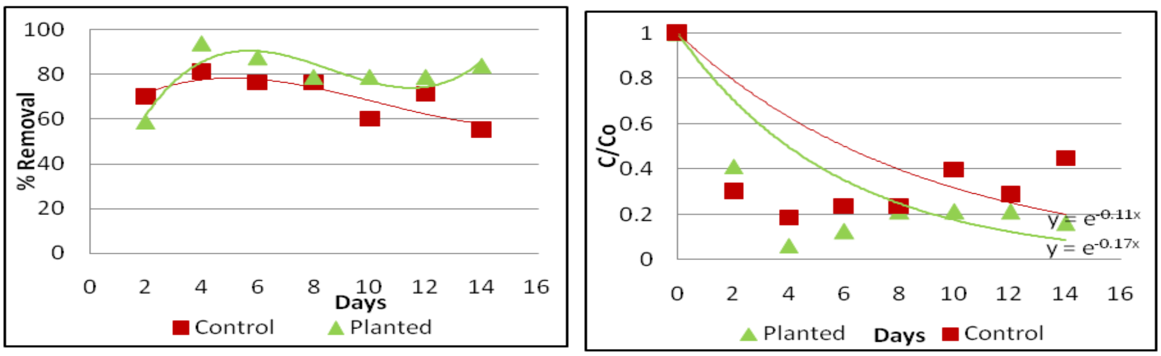
Where C_o=influent pollutant concentration (mg/L), C = effluent pollutant concentration (mg/L), *t* = nominal hydraulic retention time (day), *k* = first-order removal rate constant (day^{-1}). The Analysis of variance (ANOVA) were also use to analyses the samples.

RESULTS AND DISCUSSION

The analysis considers the removal efficiency and performance of planted and unplanted (control) of hybrid (SSF-FWS) constructed wetland systems in COD, nutrients (NH_3-N, NO_3-N and PO_4-P) and TSS removal in the aquacultures effluent.

COD removal

COD is chemical oxygen demand which measures oxygen requirement of a sample that is susceptible to oxidation using strong chemical oxidation. It is used to determine the amount of organic pollutants found in water. From Figure 2(a), the removal efficiency of COD in planted systems is higher than that in the control systems. The COD reduction achieved is up to 93.8% in only 4 days of experiment in planted and fluctuates until the end of experiment. Figure 2(b) shows that the planted system is more efficient as compared to the control system where the removal rate constant (k) of the planted system (k =0.174 day^{-1}) higher than control system (k = 0.115 day^{-1}). The reduction of COD concentration is most probably due to the reduction of the amount of organic pollutant as there are microorganism exist to breakdown the organic matter with the consumption of oxygen provided at the rhizosphere of the wetland plants (Stottmeister et al., 2003).



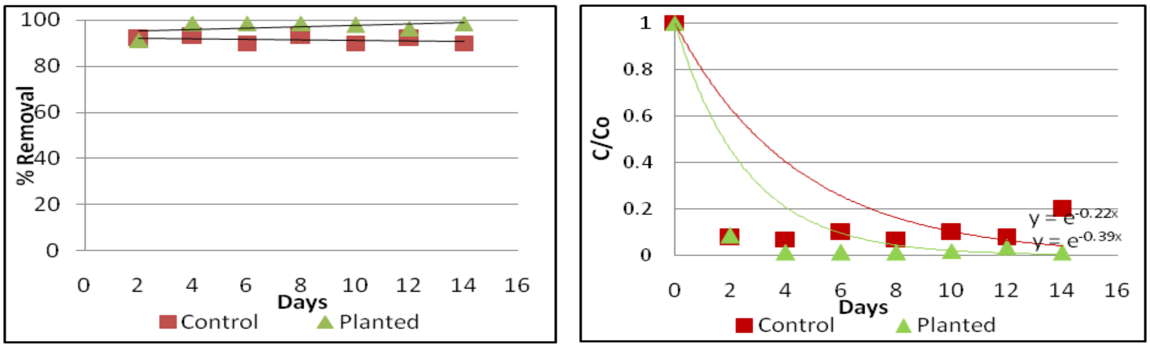
(a) (b)

Figure 2. (a) COD removal efficiency (b) Performance of COD removal analysis

Nutrients removal

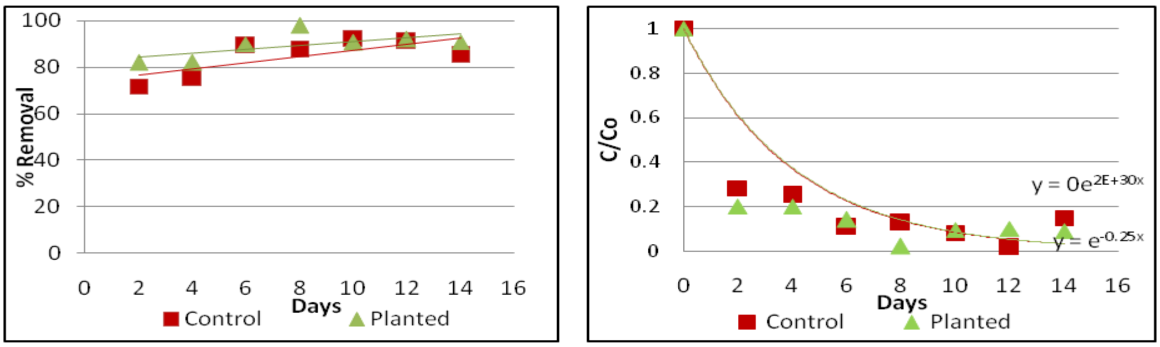
The nutrients analyzed in the hybrid SSF-FWS constructed wetland systems were ammonia nitrogen (NH_3-N), nitrate (NO_3-N) and orthophosphate (PO_4-P). Figure 3(a) presents ammonia removal percentage of SSF-FWS CW system. The system achieved 99% removal as only 4 days of treatment in the planted constructed wetland system and fluctuates till the end of experiment. Planted constructed wetland with k=0.39 day^{-1} also show the significantly different than the control with k=0.22 day^{-1} as in Figure 3(b) thus follow the first order plug flow kinetic model. The great removal efficiency of the ammonia is due to the nitrification process in the wetland system. Planted constructed wetland has greater removal efficiency of NH_3-N because of the plant uptake and the roots of the plants can supply more oxygen for the nitrifying bacteria where ammonia was converted to nitrite and then nitrate. Adsorption of ammonia by sediment could also occur; however, this would not significantly affect overall concentration since the adsorbed ammonia nitrogen would be easily released upon changes in water chemistry conditions (Kadlec and Knight, 1996).

Figures 4(a) shows the removal percentage of Nitrate (NO_3-N) in the SSF-FWS CW systems in 14 days of treatment. The average removal efficiency for the planted systems is 90.8% at the end of treatment while 85.2% for the control systems. The removal performance for both systems in Figure 4(b) shows insignificant difference as the k=0.25 day^{-1} for the planted system and k= 0.246 day^{-1} for the control system. These situation are about the same with Naylor et al. (2003) where no significant different between planted and unplanted system in nitrate removal. That maybe due to the anaerobic zones establish in both systems and denitrification was faster than nitrification, as usually in SSF CWs. Ammonification produced by the organic nitrogen breakdown which ammonia concentration remain high.



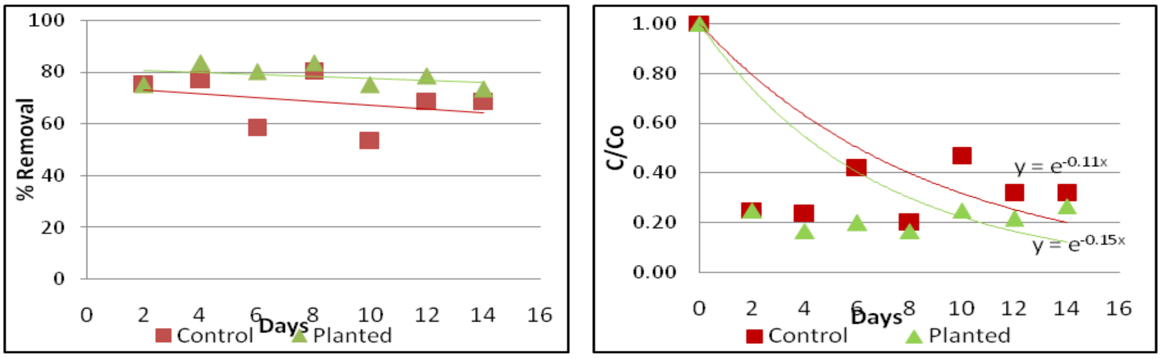
(a) (b)

Figure 3. (a) Ammonia Nitrogen (NH_3-N) removal efficiency (b) Performance of removal analysis.



(a) (b)

Figure 4. Nitrate (NO_3-N) removal efficiency (b) Performance of removal analysis.



(a) (b)

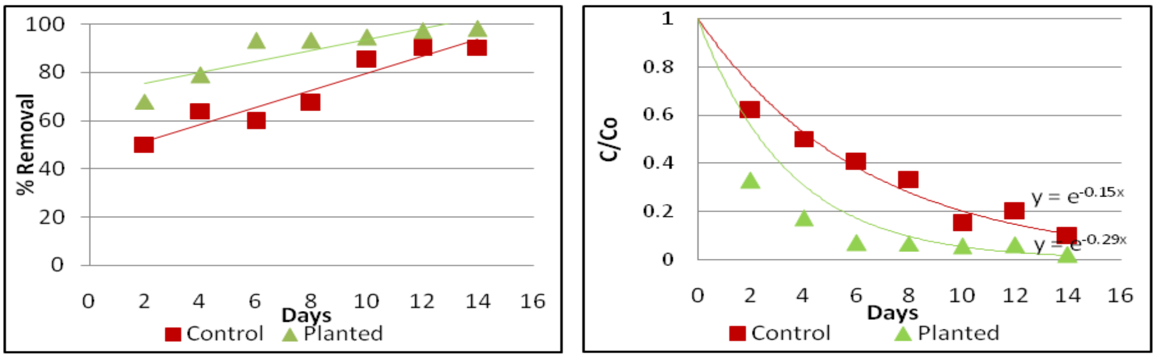
Figure 5. (a) Orthophosphate (PO_4-P) removal efficiency (b) Performance of removal performance analysis.

Figure 5(a) shows the percentage removal of orthophosphate in 14 days of treatment. At the end of experiment, the percent removal of the planted systems is 73.33 percent and the unplanted is 68 percent. As expected, the planted systems perform better as the wetland plants are taking up phosphorus for their growth. Both plants (*Eichhornia crassipes* and *Limnocharis flava*) show their potential in phosphorus uptake. From Figure 6(b) for the planted system with k=0.151 day^{-1} which is significantly higher than k= 0.115 day^{-1} for the control systems. The orthophosphate is removed by sedimentation, filtration and plant uptake in the FWS systems, whereby in the SSF tank, the orthophosphate is removed by filtration from soil and rock, sedimentation and plant uptake.

Removal of total suspended solid (TSS)

From Figure 6(a), the removal of suspended solid is very high for the planted system with 98.1% removal as compared to 90.1% in the unplanted systems. The media act as a filter by trapping solids in the wastewater. Solids are only partially sediment in the unplanted systems. The first-order removal rate constant, k from Figure 6(b) is k =0.294 day^{-1} for planted and k = 0.159 day^{-1} for the unplanted system. The achievement of both macrophyte also can help to reduce the TSS in the CW systems due their root zone that act as a filtering system and slowing down the water flow while entrap the TSS.

Table 1 summarizes the treatment performance as comparing to previous research using CW to treat many types of aquacultures effluent. This research results comparable with Naylor et al., (2003) in term of COD and TSS but not in PO_4 removal.



(a) (b)

Figure 6. (a) TSS removal efficiency (b) Performance of removal performance analysis.

Table 1. Summary of constructed wetland studies on aquacultures effluent treatment.

System type	Plant Species	Wastewater type	Pollutant Removal	References
SSF	*Phragmites australis*	Rainbow trout	95.8-97.3 TSS, 64.1-73.8 COD, 49-68.5 TP, 20.6-45.8 TN	(Schulz et al., 2003)
SSF	*Phragmites communis, Phalaris arundinacea*	Intensive trout farms effluent	90.1% TSS 61.2-87.8% TAN, 8.4% NO_3-N, 209% PO_4-P	(Sindilariu et al., 2007)
FWS-SSF	*Ipomoea aquatica Paspalum vaginatum Phragmites australis*	Fishpond effluent	40% TP 86-98% NH_4-N 95-98% TIN 32-71% PO_4-P	Lin et al., *(*2002)
FWS-SSF	*Typhal atifolia Phragmites australis*	Intensive shrimp aquaculture wastewater	55-66% TSS, 37-54% BOD, 64-66% TAN, 83-94% NO_3-N	(Lin et al., 2005)
SSF	*Phragmitesc ommunis; Typhal atifolia*	Freshwater fishfarm effluent	55-96% COD, 98-100% TSS, 48-95% TKN, 86% TP, 94% PO_4	(Naylor et al., 2003)
VSSF	*Typha latifolia; A. calamus*	Chanel catfish	56%BOD,26%COD, 58%TSS, 17% TP, 48%TN, 34%NH_4-N	(Zhang et al., 2010)
VSSF-HSSF	*Phragmites australis; Spartinaal terfloria; Scirpus mariquer*	Shrimp	67%TN, 71%TAN, 66%TSS,27%COD, 24% TP	(Shi et al., 2011)
SSF-FWS	***Limnocharis flava; Eichhornia crassipes***	**Catfish pond effluent**	**82.5% COD, 99% NH_3-N, 98%TSS, 91% NO_3-N, 73%PO_4-P**	**This study**

CONCLUSIONS

The following conclusions can be drawn from the study:

– Overall removal efficiency of planted with *Eichhornia crassipes* and *Limnocharis flava* and control hybrid CW systems on aquacultures effluent treatment, indicates the presence of macrophytes can enhance the removal efficiency of COD, nutrients and TSS with the aid of hybrid CW systems.

– The efficiency removal for planted is COD 82.5 percent, Orthophosphate 73.33 percent, Nitrate 90.8 percent, Ammonia nitrogen 98.57 percent and TSS 98.1 percent. Therefore, hybrid vegetated constructed wetland is has shown a great potential to treat the aquacultures effluent.

ACKNOWLEDGEMENTS

We greatly acknowledge the KPT for FRGS Grant No. 9003-000371.

Literature cited

APHA. (2005). Standard methods for the Examination of Water and Wastewater American Public Health Association, AWWA and WPCF, Washington DC

International Water Association. (2000). Constructed Wetlands for Pollution Control, Processes, Performance, Design and Operation. IWA Publishing, London.

Jegatheesan,V., Shu, L., and Visvanathan, C. (2011). Aquaculture effluent: impacts and remedies for protecting the environment and human health, in Nriagu Jerome (Eds.). Encyclopedia of Envi. Health. pp 123-135.

Kadlec, R.H., and Knight, R.L. (1996). Treatment wetlands. Lewis Publishers, Boca Raton, Florida.

Lin, Y.F., Jing, S.R., Lee, D.Y., and Wang, T.W. (2002). Nutrient removal from polluted aquaculture wastewater using constructed wetlands system. Aquaculture. *209*, 169-184.

Lin, Y.F., Jing, S.R., Lee, D.Y., Chang, Y.F., Chen, Y.M., and Shih, K.C. (2005). Performance of a constructed wetland treating intensive shrimp aquaculture wastewater under high hydraulic loading rate. Environ. Pollut. *134*, 411-421.

Lim, P.E. (2002). Constructed Wetland: Mechanisms of Treatment Processes and Design Models. In: Mashhor, M., Lim, P.E. and Shutes, R.B.E. "Constructed Wetlands: Design, Management and Education". Malaysia: Universiti Sains Malaysia Publisher.

Naylor, S. Brisson, Jacques Labelle, M. A., Drizo, A., and Comeau, Y. (2003) Treatment of freshwater fish farm effluent using constructed wetlands: the role of plants and substrate. Water Sci. Technol. *48*(*5)*, 215–222

Schulz, C., Gelbrecht, J., and Rennert, B., (2003). Treatment of rainbow trout farm effluents in constructed wetland with emergent plants and subsurface horizontal water flow. Aquaculture. *217*, 207–221.

Shi, Y., Zhang, G., Liu, J., Zhu, Y., and Xu, J. (2011). Performance of a constructed wetland in treating brackish wastewater from commercial recirculating and superintensive shrimp growout systems. Bioresour. Technol. *102*, 9416–9424.

Sim, C.H., Yusoff, M.K., Shutes, B., Ho, S.C., and Mansor, M. (2008). Nutrient removal in a pilot and full scale constructed wetland, Putrajaya city, Malaysia. J. Environ. Manage. *88 (2),* 307-317.

Sindilariu, P.D., Wolter, C., and Reiter, R. (2008). Constructed wetlands as a treatment method for effluent from intensive trout farms. Aquaculture.

Stottmeister, U., Wiebner, A., Kuschk, P., Kappelmeyer, U., Kastner, M., Bederski, O., Muller, R.A., and Moormann, H. (2003). Effect of plants and microorganisms in constructed wetlands for wastewater treatment. Biotechnol. Adv. *22*, 93-117

Thullen, J.S., Santoris, J.J., and Nelson, M.S. (2005). Managing vegetation in surface flow wastewater treatment wetlands for optimal treatment performance. Eco. Eng. *25(5)*, 583-593.

Vymazal, J. (2007). Removal of Nutrient in Various Types of Constructed Wetlands. Science of the Total Environment; *380*, 48-65.

Vymazal, J. (2010). Constructed Wetlands for Wastewater Treatment. Water. http://doi.org/10.3390/w2030530

Vymazal, J. (2013). The use of hybrid constructed wetlands for wastewater treatment with special attention to nitrogen removal: A review of a recent development. Water Res. http://doi.org/10.1016/j.watres.2013.05.029

Zhang, S., Zhou, Q., Xu, D., He, F., Cheng, S., Liang, W., Du, C., and Wu, Z. (2010). Vertical flow constructed wetlands applied in a recirculating aquaculture system for channel catfish culture: Effects on water quality and zooplankton. Polish J. Environ. Stud. *19*, 1063–1070.