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Observation of Nitrogen and Phosphorus Removals and Accumulations in Surface Flow Constructed Wetland (SFCW)

Suntud Sirianuntapiboon [a] and Prapa Sohsalam [b]

[a] *Department of Environmental Technology, School of Energy Environment and Materials, King Mongkut's University of Technology Thonburi (KMUTT), Bangkok 10140, Thailand.*
[b] *Division of Biology, Faculty of Liberal Arts and Sciences, Kasetsart University, Kamphaeng Saen Campus, Kampaeng Saen, Nakhonpathom 73140, Thailand.*

Abstract

The tropical emergent plant species; *Cyperus involucratus, Canna siamensis, Heliconia* sp., *Hymenocallis littoralis, Typha augustifolia* and *Thalia dealbata* were used to observe nutrients (total phosphorus: TP and total nitrogen: TN) removal efficiencies of surface flow constructed wetland (SFCW). The system was operated at different hydraulic retention time (HRT) of 1, 3 and 5 days and the average atmospheric temperature of 29.1 ± 4.9°C. The seafood industrial wastewater was employed as the influent. The high biomass production plant species; *Cyperus involucratus, Typha augustifolia* and *Thalia dealbata* could generate the high oxidative environment. Amount of N and P accumulations in plant tissue were increased with the increase of plant biomass production. The system did not show any significantly different on N and P accumulations among the tested-emergent plant species. But the amount of accumulated-N and P were increased with the increase of HRT. N accumulations in plant tissue, effluent, sediment and media of the system with the tested-emergent plant species under HRT of 1-5 days were in the range of 2.17-43.80%, 7.91-27.75%, 19.62-36.86% and 14.39-31.88%, respectively. Also, P accumulations were 0.79-17.01%, 20.35-28.37%, 40.96-56.27% and 9.09-20.47%, respectively.

Keywords: nitrogen; nutrients accumulation; phosphorus; seafood industrial wastewater; durface flow constructed wetland.

1. Introduction

The increase of wastewater whether from agriculture, domestic or industry created challenges for those seeking cost effective treatment method (Fraser *et al*., 2003, Steer *et al*., 2003). Reactive nitrogen production, much of which becomes biologically available nitrogen has increased by over an order of magnitude from 1,860 to 2,000 (15-165 Tones/year). That was due to fertilizer production, the increased activity of nitrogen-fixing organisms and the result of fossil fuel combustion (Galloway *et al*., 2003; Vitousek *et al*., 1997). Significant amounts of this excess nitrogen are transported as nitrate-nitrogen into river and streams, leading to eutrophication and episodic hypoxia (dissolved oxygen of less than 2 mg/L) in coastal waters worldwide (Sherwood *et al*., 1995). Wetlands are normally used as tertiary treatment to remove nitrogen (N) and phosphorus (P) from the effluent of secondary treatment step before discharging into reservoir (Kadlec, 1987). Both N and P caused the pollution of surface water as eutrophication and N as NO_3^- is associated with groundwater pollution (Metcalf & Eddy, 2004). Nitrification and denitrification mechanisms of wetland were strongly effective to reduce nitrogen compounds of raw or treated wastewaters (Gale *et al*., 1993a; 1993b). Microbial processes driven for above mechanisms as nitrification process; converted organic and ammonia nitrogen to be nitrite and nitrate which can be converted to be nitrogen gas by denitrification process (Dafner, 1992; Hammer and Knight, 1994). Several researchers (Boyt *et al*., 1977; Fetter *et al*., 1978; Schwartz, 1989) suggested that freshwater wetlands, swamps, marshes and flooded soil systems could reduce P concentration of the wastewater. Richardson (1985) reported that wetland soils could function as the adsorbent. Physical, chemical and biological functions in both liquid (water body) and solids (sediment and media) portions of wetland dynamically regulated N and P removals and accumulations and N and P could be removed through the uptake process of macrophyte and algae (Kloptek, 1975; Syers *et al*., 1973; Toth, 1972). Kadlec (1989) also reported that N and P removal yields were due to amount of fall leaf and sediments.

Even Surface Flow Constructed Wetland; SFCW, was widely used as tertiary treatment of the wastewater treatment system for N and P removals. But a few researchers studied on the nutrients removal and

Table 1. Chemical properties of the seafood wastewater ± standard deviation

Chemical parameter	Unit	Value
BOD_5	mg/L	358.4 ± 31.4
Suspended Solid	mg/L	93.9 ± 14.5
Total Nitrogen	mg/L	90.2 ± 2.5
Ammonia	mg/L	36.5 ± 4.3
Nitrate	mg/L	23.4 ± 0.6
Organic nitrogen	mg/L	30.4 ± 5.3
Total Phosphorus	mg/L	41.0 ± 5.4
Phosphate	mg/L	15.1 ± 1.7
Organic phosphorus	mg/L	25.9 ± 4.9

accumulation by plant uptake and in media and sediment in the tropical zone. Then, the purposes of this work are to determine the effects of HRTs and emergent plant on nutrients (N and P) accumulations in each wetland component as plant tissue, media and sediment. Six tropical emergent plant species as umbrella sedge (*Cyperus involucratus*), canna (*Canna siamensis*), heliconia (*Heliconia* sp.), spider lily *(Hymenocallis littoralis*), cattail (*Typha augustifolia*) and water canna (*Thalia deabata*) were selected as the represented species. A high organic concentration wastewater from the seafood industrial factory was used as influent of SFCW to investigate nutrients (N and P) removal and plant uptake performance.

2. Material and Methods

2.1. Selected wastewater

The seafood industrial wastewater (SFWW) was selected for this study. However, the used of raw wastewater from the process was unsuitable resulted by high impurities. Then, the reduction of impurities of the wastewater by dilution was considered. Then, the raw seafood industrial wastewater was mixed with the treated wastewater at the ratio of 1:1 before used as the influent (MSFWW) of SFCW. The wastewater treatment system of selected seafood industrial factory consisted of primary sedimentation pond, facultative pond (HRT of 14 days) and aerated lagoon (HRT of 6 hours) as shown in Fig. 1. The chemical properties of the influent (MSFWW) of SFCW were shown in Table 1.

2.2. Emergent plant species for designed-SFCW

The tropical emergent plants were used in this study. Six emergent plant species as umbrella sedge (*Cyperus involucratus*), canna (*Canna siamensis*), heliconia (*Heliconia* sp.), spider lily (*Hymenocallis littoralis*), cattail (Typha augustifolia) and water canna (*Thalia deabata*) were selected as the represented species in tropical regions.

2.3. Designed SFCW

The designed-SFCW system (Fig. 1) located in King Mongkut's University of Technology Thonburi (KMUTT), Bangkok, Thailand (latitude 13.45N and longitude 100.35E) was used in this study. The size of each microcosm cell was 0.6 x 2.0 x 0.5 m (width x length x depth), and a bed slop of 1%. The empty-bed volume of each cell was approximately 0.6 m. The inner wall of the concrete cell was painted with waterproofing paint to prevent potential leakage. Each microcosm cell was filled with gravel (1.34–1.55 cm in diameter). The element content of gravel was shown in Table 2. A 0.5 Hp water-pump (0.5 inch diameter of pipe) was used to transfer MSFWW from a storage tank to each microcosm cell and the exceed flow was re-circulated back to storage tank for homogeneous mixing. Upon entering each microcosm, the wastewater was flowed down through the permeable brick into the treatment zone. A transparent roof covered the system to prevent raining water. Each microcosm cell was divided into 2 zones as settling and treatment zones. In the settling zone, an empty gap was partitioned with an acrylic plate (0.5 m wide x 0.35 m deep x 4 mm thick) on top

Table 2. Element content (percent) of wetland media; small rock (gravel)

Element	percent	Element	percent	Element	percent
Oxygen; O	57.08	Titanium; Ti	0.12	Barium; Ba	≤ 0.01
Calcium; Ca	29.59	Sulfur; S	0.08	Chromium; Cr	≤ 0.01
Silicon; Si	6.73	Strontium; Sr	0.06	Nickel; Ni	≤ 0.01
Aluminum; Al	2.53	Phosphorus; P	0.02	Rubidium; Rb	≤ 0.01
Magnesium; Mg	1.44	Zirconium; Zr	0.01	Cercium: Ce	≤ 0.01
Iron; Fe	1.10	Fluorine; F	≤ 0.01	Niobium; Nb	≤ 0.01
Potassium; K	1.00	Chlorine; Cl	≤ 0.01	Yttrium; Y	≤ 0.01
Sodium; Na	0.24	Manganese; Mn	≤ 0.01		

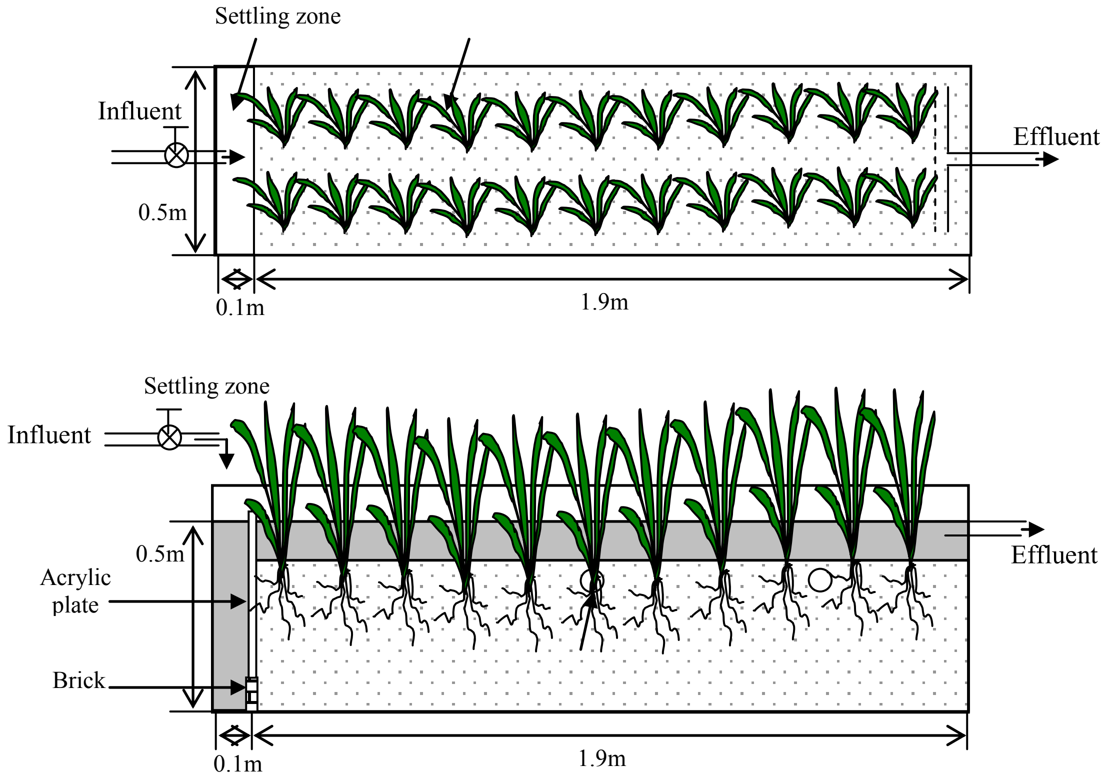

Figure 1. Dimension of constructed wetland of top view (top) and side view (bottom)

of a 0.15 m water-permeable brick resulted to remove suspended solids from MSFWW. This also prevented short circuiting of flow. Initially, 22 stems of emergent plant, were taken from the nearby swamp, were planted in the treatment zone.

2.4. SFCW operations

The schematic of the SFCW operations was illustrated in Fig. 2. The designed-SFCW system with six emergent plant species was operated with MSFWW under various HRTs of 1, 3 and 5 days. Each experiment was operated for over 90 days. The effluent and influent of each microcosm cell were collected for chemical analysis. Harvested plant (aboveground and belowground), media and sediment were also sampled for chemical analysis. The experiments were conducted during January- December, 2010.

2.5. Water sampling and chemical analysis

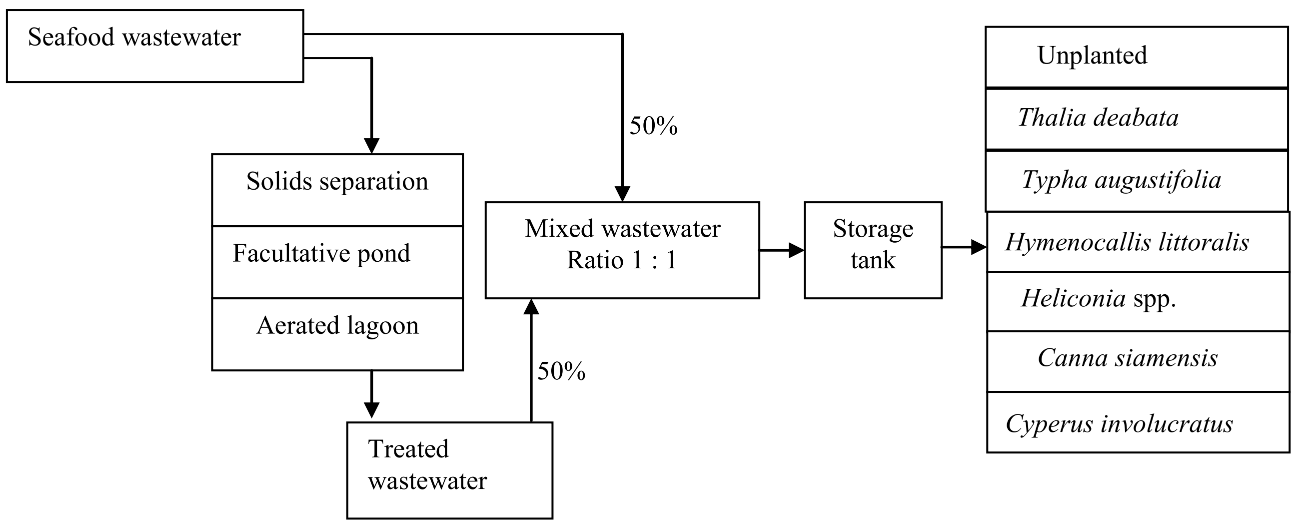

Figure 2. Schematic diagram for newly built constructed wetland for treating seafood wastewater which was mixed with wastewater from pretreatment units including sedimentation pond, facultative pond and aerated lagoon.

100-ml samples (both influent and effluent) were taken three times a week from influent port and outflow end of each microcosm cell. Sampling was usually conducted at approx.10 A.M. on each sampling date. The dissolved oxygen, oxidation reduction potential (ORP) and pH were measured on-site by using dissolved oxygen meter (YSI oxygen probe), potentiometer (Metrohm 744 probe) and pH-meter, respectively (APHA, 1995). Other chemical parameters were performed immediately after the samples were transported to the laboratory. N and P of effluent and influent were analyzed as ammonia nitrogen (NH_4^+-N), nitrite nitrogen (NO_2^--N), nitrate nitrogen (NO_3^--N), organic nitrogen (organic-N), total nitrogen (TN), orthophosphate and total phosphate as phosphorus (TP), respectively, by using the standard methods for water and wastewater determinations (APHA, 1995).

2.6. Plant tissue analysis

Plant tissue samplings were conducted following each HRT experiment. Two types of plant tissue sample were collected as aboveground plant tissue (shoot) and belowground plant tissue (root). The samples were oven dried at 105°C for 2 h. TN in plant tissue was determined using an induction furnace and a thermal conductivity detector. Samples were ignited in an induction furnace at approximately 900°C, under a helium and oxygen environment in a quartz combustion tube. An aliquot of the combustion gases was then passed through a copper catalyst to remove oxygen and convert nitrous oxides to N2, scrubbed of moisture and carbon dioxide, and the nitrogen content determined by thermal conductivity (AOAC, 1997). TP in plant tissue was determined using a nitric acid/hydrogen peroxide microwave digestion followed by atomic absorption spectrometry (AAS) and inductively coupled plasma atomic emission spectrometry (ICP-AES) (Mayer and Keliher, 1992; Sah, 1992; Meyer, 1992).

2.7. Gravel media and sediment analysis

Gravel media was weighted and 100-mL of deionized water was then added. The sample was then horizontally shaken at 120 rpm for 30 minutes to remove the biofilm. The suspension containing biofilm was next analyzed for TN and TP using the same method as that employed for plant tissue analysis. The wetland sediment was dried at 105°C for 2 h and weighted before TN and TP analysis.

2.8. Statistical analysis

All statistical tests were performed using SPSS 14.0 by SPSS Inc. In all cases, significance was defined by $p<0.05$. Test for significant difference in water quality between hydraulic retention times and plant species of the treatment wetland were tested using a completely randomized design (CRD) analysis of variance (ANOVA) with a posteriori LSD (SAS Institute, 1996).

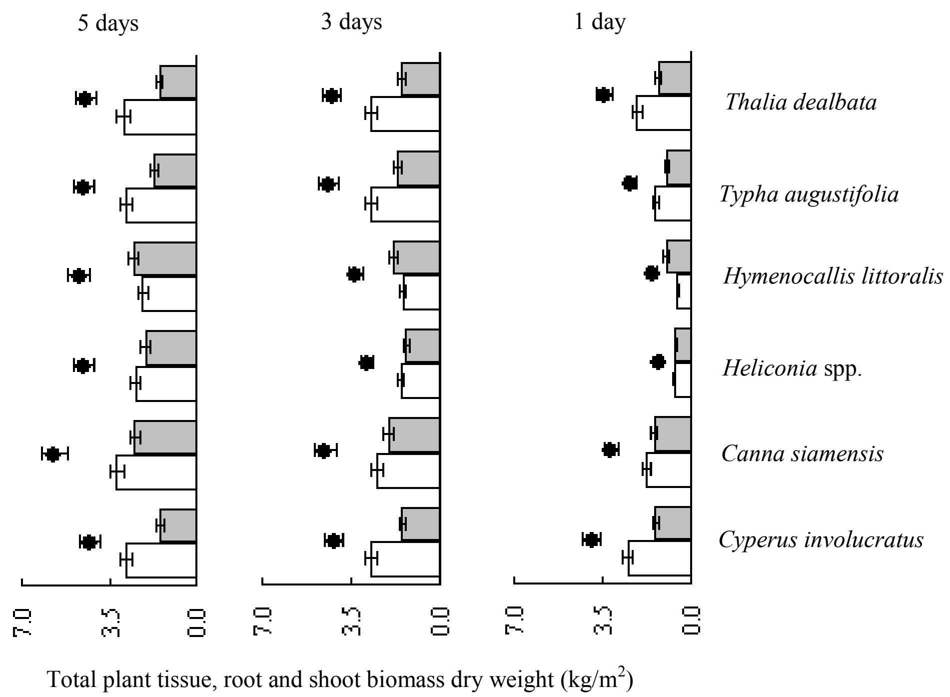

Figure3. Total plant tissue, root and shoot biomass dry weight (kg/m^2) at 5, 3 and 1 days of HRT. Symbol: ● ; Total plant tissue, ▩ ; root, □ ; shoot.

3. Results and Discussions

The experiments were done at King Mongkut's University of Technology, Thonburi, Bangkok (latitude 13.45N and longitude 100.35E), which is located in a tropical climate zone. The ambient temperatures during experimental operation were recorded at 29.1±4.9°C by Thailand meteorological department. And the highest ambient temperature of 32.2°C and lowest ambient temperature of 25.3°C were observed on the middle of April, 2010 and end of December, 2010, respectively.

3.1. Plant biomass productivity and nutrient uptake

As illustrated in Fig. 3, the plant biomass production yield of the wetland system was associated with the selected emergent plant species. The highest biomass production yield of the system was observed at a HRT of 5 days. The biomass production yields of the emergent plant species were increased with the increase of HRT except for *Cyperus involucratus* as shown in Fig. 3. Also, biomass production yields of belowground tissue (root) and aboveground tissue (shoot) were increased with the increase of HRT. And the ratio of shoot and root biomass were 1.82, 1.22, 1.16, 0.80, 1.64 and 1.83 for *Cyperus involucratus, Canna siamensis, Heliconia* sp., *Hymenocallis littorallis, Typha augustifolia* and *Thalia dealbata*, respectively. And 90% belowground portion was rhizomatous that facilitated nutrients uptake and oxygenation (Armstrong and Armstrong, 1988). This might be the disadvantage of the system for nutrients (N and P) removal, because, N and P were assimilated into both shoot and root. But for harvesting step of wetland system operation, only aboveground tissue was cut and removed from the system but the belowground tissue still remained in the system. However, the high growth of shoot gave the other advantage to epiphytic plant growth because the surface of shoot was the substrate for attachment. Gerberg *et al*. (1986) also reported that microbial nutrients transformations were the main treatment mechanism of wetland system. N and P uptake yields of emergent plants were varied among species as shown in Fig. 4. *Cyperus involucratus, Typha augustifolia* and *Thalia dealbata* showed high N uptake while *Canna siamensis* and *Hymenocallis littoralis* showed high P uptake. N and P uptakes of shoot tissue were higher than that of root tissue. N and P uptake yields of the emergent plant species were associated with biomass production yield. However, N and P contents in the plant biomass were almost same in all cases of HRTs tested. The growth of emergent plants near inlet of macrocosm cell was higher than that of outlet resulted by the higher nutrients concentration on the inlet area (Radojevic'and Bashkin, 1999). Aerts and Decaluwe (1994) also reported that the total productivity of *Carex* spp. could be increased by adding nutrients. Moreover, N and P uptakes for *Cyperus involucratus, Thypha augustifolia* and *Thalia dealbata* were ranged at 685-1,286 kg-N/ha and 102-194 kg-P/ha, respectively that was higher than the previous report done by Ennabili *et al*. (1998)

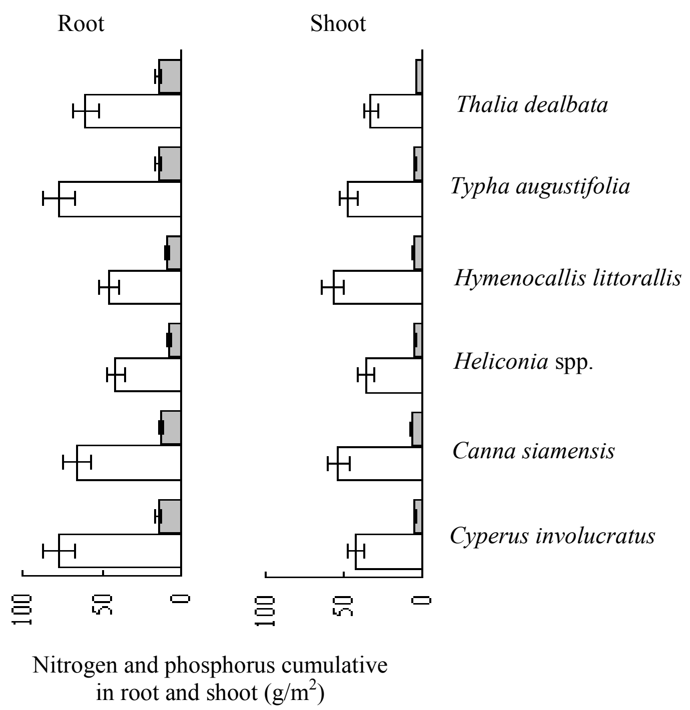

Figure 4. Average nitrogen and phosphorus accumulation in root and shoot biomass (g/m^2). Symbol: □ ; nitrogen (N), ■; phosphorus (P)

of 923 kg-N/ha and 105 kg-P/ha, respectively. Root tissue showed higher N and P contents (2.13-2.48% and 0.50-0.53%, respectively) than shoot tissue (2.86-3.01% and 0.58-0.61%, respectively). It could be suggested that root tissue acted as a food storage compartment for survival if insufficient nutrient were presented (Ennabili *et al*., 1998). A long HRT was also increase the nutrients uptake rate. This could confirm that N and P accumulations were increased with the increase of HRT as shown in Fig. 5 and Fig. 6. For the observation of N and P accumulations in the designed-SFCW system, the observed-N accumulations were 25-38%, 13-20% and 2-6% of influent-N at HRT of 5, 3 and 1 days, respectively and they were 11.5-14.7%, 4.6-6.0% and 0.7-2.1% in the case of P. It was the advantage of the wetland according to the high N uptake (Sherwood *et al*., 1995) and about 12-16 % of N was removed by plant uptake as shown in Fig. 5.

3.2. Nitrogen and phosphorus accumulation in each wetland components

Ammonia and organic nitrogen were the dominantly nitrogen compounds in the wastewater. P was primarily organic phosphorus as shown in Table 1. N loading rates of 25.0, 41.7 and 125.1 kg NH_3/ha.day and 58.5, 97.6 and 292.7 kg TN /ha.day at HRTs of 5, 3 and 1 days, respectively was applied for operating the designed SFCW. The results showed that *Cyperus involucratus* could remove ammonia, nitrate and TN from wastewater with high efficiency at all HRTs tested (data not shown). Also, about 72-78 percentage of P was removed. Reduction of HRT affected N removal performance significantly for all emergent plant species tested, but it has no effect on P removal. Moreover, the N and P removal efficiencies were increased with the increase of influent N and P concentrations. This phenomenon was similar to the report of Kedlac and Knight (1996). The reduction of HR also effected N and P accumulations in each wetland components as shown Fig. 5 and Fig. 6. N and P contents of the water body were increased with the decrease of HRT. Most N and P were accumulated in the sediment. This indicated that main nutrients (N and P) removal mechanisms were sedimentation process, plant uptake and microbial assimilation. N and P accumulations in plant tissue were decreased with the decrease of HRT as shown in Fig. 5 and Fig. 6. The various forms of N and P were continually involved in chemical and biological transformations between inorganic and organic compounds (Kedlac and Knight, 1996; Metcalf & Eddy, 2004). The system with various species of emergent plant did not show any significant different on the N and P accumulations yields in the sediment, but they gave most difference in the plant tissue as shown in Fig. 5 and Fig. 6. For the conclusion, the N accumulations of the system with various

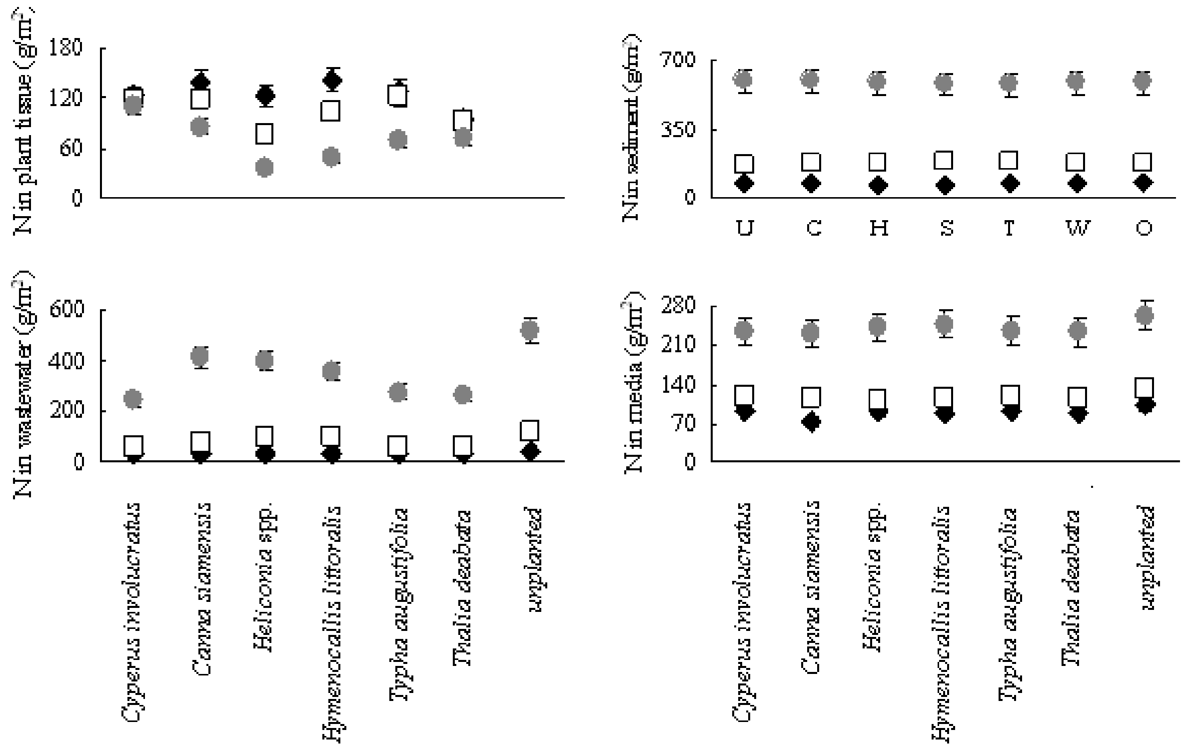

Figure 5. Total nitrogen accumulation in each part of wetland system, Symbol: ○ ; HRT 5-day, ◆ ; HRT 3-day, □ ; HRT 1-day

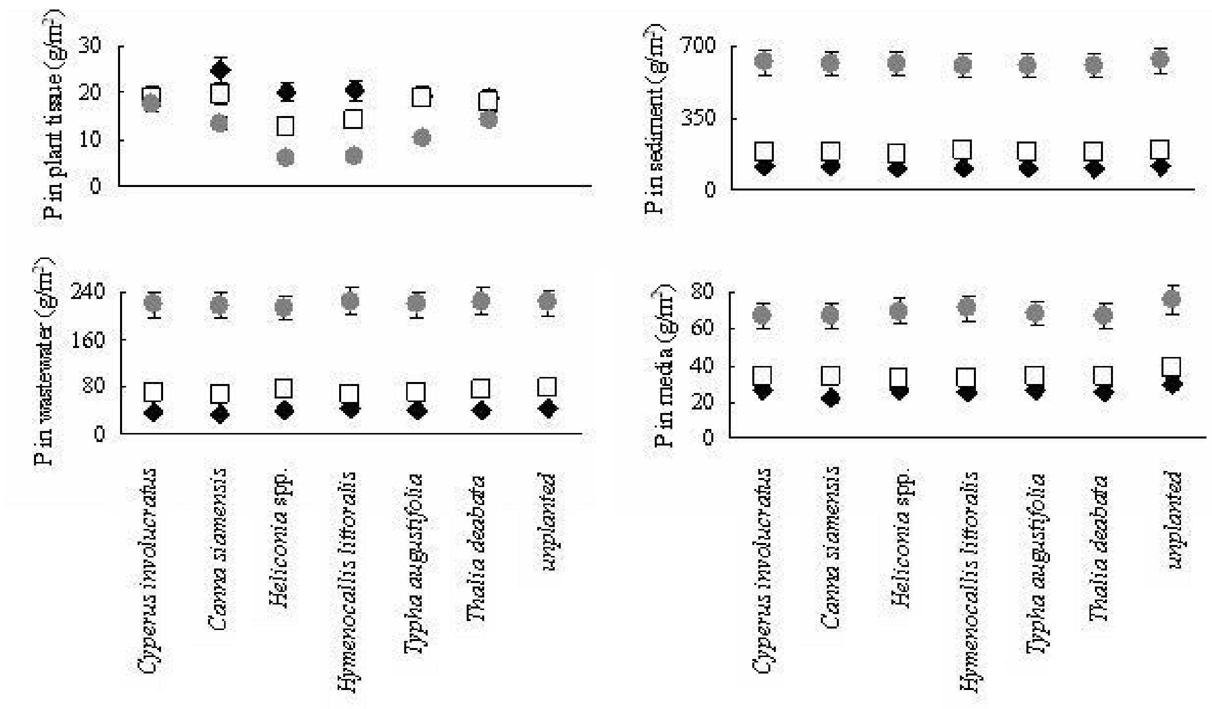

Figure 6. Total phosphorus accumulation in each part of wetland system, Symbol: ◆ ; HRT 5day, □ ; HRT 3day, ○ ; HRT 1day

species of emergent plant were in ranges of 2.17-43.80%, 7.91-27.75%, 19.62-36.86% and 14.39-31.88% in plant tissue, treated wastewater, sediment and media, respectively. And they were in ranges of 0.79-17.01%, 20.35-28.37%, 40.96-56.27% and 9.09-20.47%, respectively in the case of P accumulations.

3.3. Mass balance of nitrogen and phosphorus

As illustrated in Fig. 7, N and P accumulations in the system were increased with the decrease of HRT. Because, the reduction of HRT or increasing the organic loading rate caused an increase in an oxidation-reduction potential (ORP) value as shown in Fig. 8.

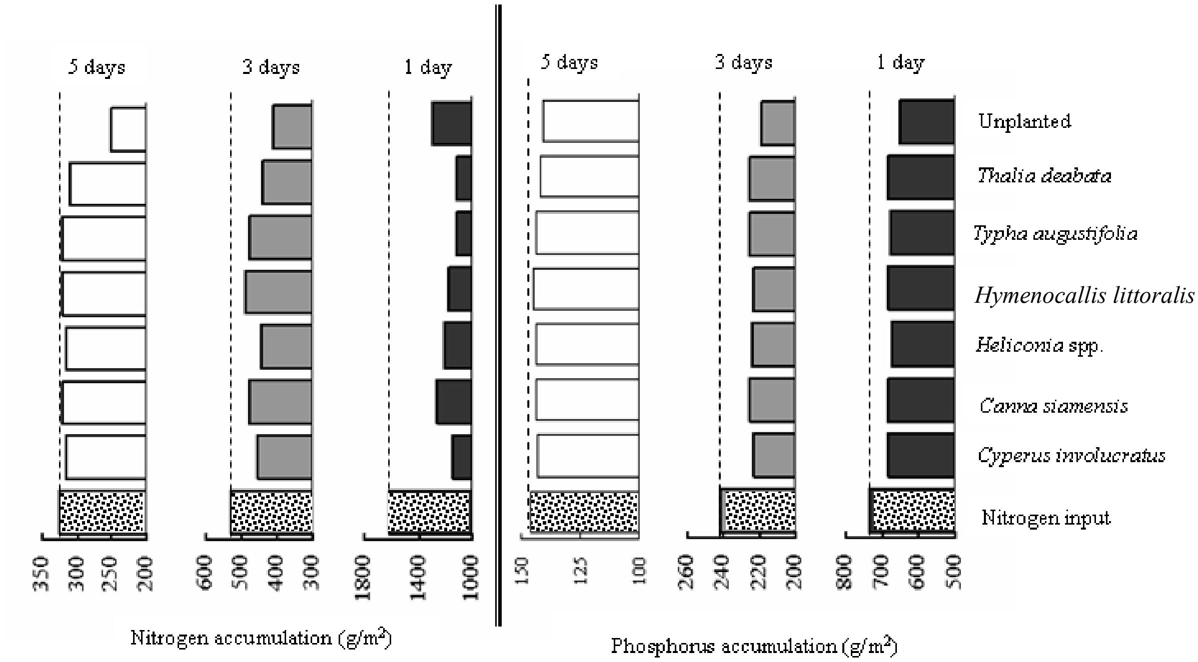

Figure 7. Nitrogen and phosphorus accumulation in SFCW at each HRT

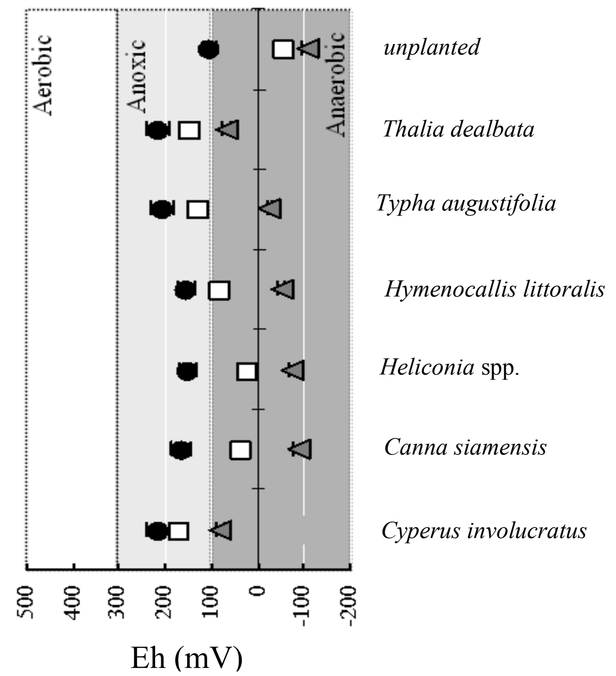

Figure 8. Oxidation Reduction potential, ORP (mV) in effluent at HRT of 5, 3 and 1 days. Approximate zones corresponding to aerobic, anoxic and anaerobic conditions are shown. Symbol: ● ; 5 days, □ ; 3 days, △ ; 1 day

Nitrate reduction; denitrification occurred under low dissolved oxygen level (anoxic condition) (Kedlac and Knight, 1996). Then, it could suggest that N could be loss from the wetland system under a high organic loading. A gaseous form of phosphorus; phosphine (PH_3) was identified as a potential compound of significance in wetland environment (Richardson, 1985). PH_3 could be dissolved in water, but it had high vaporization. It might be emitted from regions of extremely low redox potential similar to methane. Devai *et al*., (1988) reported that PH3 could be released from a constructed wetland (1.0 ha, *Phragmite* and bulrushes) as the rate of 1.7 g/m^2/year of phosphorus. Then, our experiments, P was lost as plant litter and PH_3. According to plant biomass production, the higher biomass production species were characterized by more positive ORP value (*Cyperus involucratus, Typha augustifolia* and *Thalia dealbata*). A comparison between the planted and unplanted SFCW systems, indicated that effluents of NH_4^+-N and NO_3^--N of unplanted-SFCW system were higher than those of planted-SFCW system. P was more rapidly depleted by unplanted-SFCW system than planted-SFCW as shown in Fig. 9. This indicated that the unplanted-SFCW system presented a more reductive environment. Because emergent plant had the ability to adsorb oxygen and other needed gasses from the atmosphere through their leaves and above-water shoot, and then, transferred to the root. Therefore, their root was sustained aerobically environment. It could estimate that these plants can transfer about 5-45 g of oxygen/day/m^2 of wetland surface area, depending on plant density and oxygen stress levels in the root zone (Sherwood *et al*., 1995).

5. Conclusion

The experiments demonstrated that the reduction of HRT effected to decrease N and P accumulations in plant tissue, media, sediment and effluent. The tropical plant species; *Cyperus involucratus, Canna siamensis, Heliconia sp., Hymenocallis littoralis, Typha augustifolia* and *Thalia dealbata* did not show any significantly different on N and P accumulations in shoot and root. The high biomass production species (*Cyperus involucratus, Typha augustifolia* and *Thalia dealbata*) exhibit a higher oxidative environment in the SFCW system according to oxygen transferred through their leaves and above-water stems to rhizosphere. Reduction of HRT effected to plant biomass production and also affected N and P accumulations in plant tissue. N and P accumulations in plant tissue were associated with plant biomass production yields. Reduction of HRT or increasing of OLR resulted to increase N and P accumulation yields

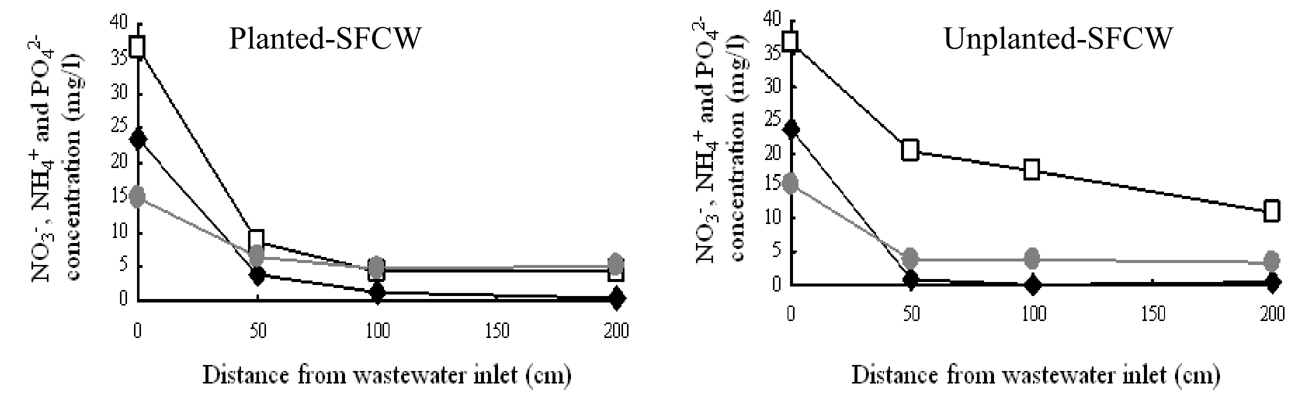

Figure 9. Nitrate, ammonia and phosphate concentration at each sampling point in planted and unplanted SFCW systems. Symbol: ◆ ; nitrate, □ ; ammonia, ● ; phosphate

in water body as well as sediment and media (gravel). Then, the high N and P accumulations could be observed under high OLR and HRT operations.

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Nomenclature

HRT:	Hydraulic retention time
MSFWW:	Mixed food industrial wastewater
N:	Nitrogen
NH_4^+-N:	Ammonia nitrogen
NO_2^- -N:	Nitrite nitrogen
NO_3^- -N:	Nitrate nitrogen

ORP:	Oxidation reduction potential
P:	Phosphorus
SFCW:	Surface flow constructed wetland
SFWW:	Sea food industrial wastewater
TN:	Total nitrogen
TP:	Total phosphorus

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Correspondence to
Professor Dr. Suntud Sirianuntapiboon,
Department of Environmental Technology,
School of Energy Environment and Materials,
King Mongkut's University Thonburi,
Bangkok 10140,
Thailand
Tel. +662-4708656
Fax. +662-4708660
E-mail: suntud.sir@kmutt.ac.th