EFFICIENCY OF VETIVER GRASS CULTIVATED WITH FLOATING PLATFORM TECHNIQUE IN DOMESTIC WASTEWATER TREATMENT

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ABSTRACT

This study was aimed to compare the treatment efficiencies of two *Vetiveria zizaniodes* (L.) Nash ecotypes, i.e. Songkhla3 and Surat Thani, planted in different wastewater strengths utilizing hydroponic technique. The twelve plastic containers of 0.85 x 1.55 x 0.50 m^3 each (width x length x height) were set up and separated into 3 groups, planting with Songkhla3 ecotype, Surat Thani ecotype, and no plants as control. Sixty vetivers, which their shoots and roots were pruned to 20 and 13.5 cm, were planted on foamed board in each container. Two different strengths of domestic wastewater, i.e. HCW (high concentration wastewater) and LCW (low concentration wastewater) were continuously distributed to each group. The average BOD, TKN and TP of HCW were 90.12-94.88, 41.025-52.806 and 5.892-6.657 mg/l, respectively, whereas the average of LWC were 44.28-58.92, 34.731-42.144 and 4.838-5.482 mg/l, respectively. The study was divided into 3 phases of 8 weeks each, using 7-, 5- and 3-day detention times, respectively.

The results indicated that the treatment efficiencies of different detention times and wastewater concentrations were significantly different. The 7-day detention time posted highest treatment efficiency. The treatment efficiencies of BOD, TKN, TP and ortho-PO_4 in HCW were higher than in LCW, with the average of 90.54-91.46, 61.01-62.48, 17.78-35.87 and 15.40-23.46%, respectively. But the treatment efficiency of NH_3-N in LCW was higher than in HCW, with average of 50.22-58.62%. The treatment efficiencies of Songkhla3 and Surat Thani ecotypes were not significantly different. However, the treatment efficiencies of BOD, TP and ortho-PO_4 of Surat Thani ecotype were slightly higher than Songkhla3 ecotype. The biomass increment of Songkhla3 ecotype in HCW was higher than in LCW, whereas Surat Thani ecotype showed the opposite trend. The nutrient accumulations in shoots and roots of both ecotypes were generally increased with wastewater concentration. The highest nutrient accumulation in roots was found in 7-day detention time. In conclusion, the overall results suggested that the optimal condition of vetivers cultivated with floating platform technique in domestic wastewater treatment should be designed at 7-day detention time and planted with Surat Thani ecotype. However, if wastewater had high nutrients, Songkhla3 ecotype should be planted.

Keywords: ecotypes, domestic wastewater, detention time, continuous flow

INTRODUCTION:

Currently, Thailand is facing the ever-increasing problems of declining water quality, mainly due to contamination of various pollutants in water, making it unsuitable for consumption and other usages.

Phytoremediation, the use of plants for environmental restoration, is an emerging clean up technology to exploit plant potential to remediate soil and water contaminate with a variety of pollutant compounds (Lasat, 2002). Phytoremediation is environmental friendly, inexpensive and can be carried out in polluted place (remediation in si tu).

Vetiver grass (*Vetiveria zizaniodes* (L.) Nash), a perennial grass, is fast growing grass with a deep root system, high biomass production and high efficiency of photosynthesis. Due to its unique morphological and ecological characteristics including its tolerance high levels of heavy metals and adverse environmental conditions, vetiver grass has been used effectively for many applications such as steep slope stabilization and environmental protection (Xia and Liu, 1998). The utilization of vetiver system for wastewater treatment is a new and innovative phytoremediation technology (Troung, 2003). Vetiver system is green, simple, practicable and cost-effective. The more important benefit is the fact that by-product from the system offers a range of uses for handicrafts, thatches, animal feed, much, manure, and organic source for composting (Smeal, et al., 2003). *V. zizaniodes* is not a hydrophyte but it prefers wet and waterlogged habitat where it can grow and develop eventhough a large portion of its shoots are submerged for relatively long period, normally in water. Many scientists have confirmed that it is powerful to remove nitrogen and phosphorus from water and, therefore, is a good plant for purifying eutrophic water (Zheng et al., 1997). In addition, the results from recent research revealed that it has ability to absorb and to tolerate extreme levels of nutrients (Wagner, et al., 2003).

The aims of the present study are, therefore, to: (1) compare the efficiencies of two vetiver ecotypes in treating domestic wastewater of different strengths using hydroponic technique (2) determine the growth and the degree of nutrient accumulation in two vetiver ecotypes received different wastewater strengths.

MATERIALS AND METHODS:

The experiments were carried out under well-ventilated temporary greenhouse at Chulalongkorn University, Bangkok, Thailand. The twelve plastic containers of 0.85 x 1.55 x 0.50 m^3 each (width x length x height) were set up together with the inlet pipe and valve connected to the water storage tank. The water depth was maintained at 0.4 m. The outlet pipe was placed at approximately 5 cm below water surface (Figure 1). The containers were separated into 3 groups, each group was planted with Songkhla3 ecotype, Surat Thani ecotype, and no plants as control. Two different domestic wastewater strengths, i.e. HCW: high concentration wastewater (which was treated by screening) and LCW: low concentration wastewater (which was treated by anaerobic filter), were continuously distributed to each group.

The foamed board which a dimension of 0.6 x 1.2 x 0.025 m^3 (width x length x height) was placed on water surface as the floating platform. Each foamed board, the sixty 4.5 cm diameter holes with 10 x 10 cm^2 intervals were made. Each hole was covered with sponge for holding vetiver. Similar size vetivers were selected and then pruned to 20 cm. for the shoots (stems and leaves) and 13.5 cm for the roots. Each vetiver was planted onto a hole in platform (Figure 2). Thus, approximately 10 cm of roots were submerged under wastewater.

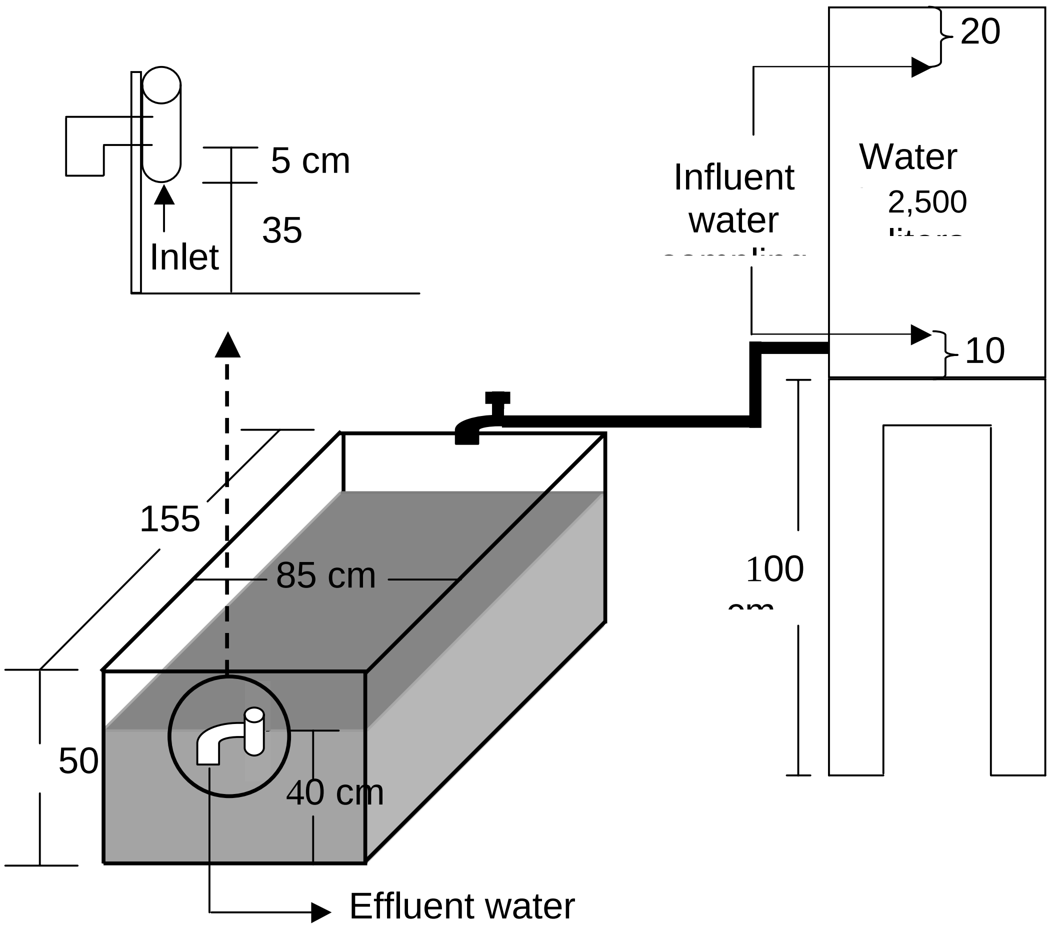

Figure 1   Experimental designed system and water sampling locations

The experiment was divided into 3 phases, according to the detention times, i.e. 7-, 5- and 3-day detention times with the flow rates of 0.075, 0.105 and 0.176 m^3/day, respectively. Each phase was conducted for 8 weeks. At the end of each phase, the treated vetivers were removed. The influent and effluent were sampled at weekly interval and analyzed for pH, DO, BOD, TKN, NO_3-N, NH_4-N, TP and ortho-PO_4 according to standard methods for water and wastewater analysis (AWWA, WEF and APHA, 1998).

The growth of vetivers in term of height and number of the new shoots and roots produced were recorded on alternate week basis. At the beginning and at the end of each experiment, the biomass of shoots and roots were studied. In addition, the concentrations of nutrients (TN and

TP) accumulated in shoots and roots were determined according to standard methods (AOAC, 2003).

The mean and standard deviation values of replicate samples were calculated. The collected data were treated with one way analysis of variance (ANOVA) to test for the significant difference between wastewater strengths, vetiver ecotypes and detention times. The Duncan's new multiple range test at 5% probability level were calculated.

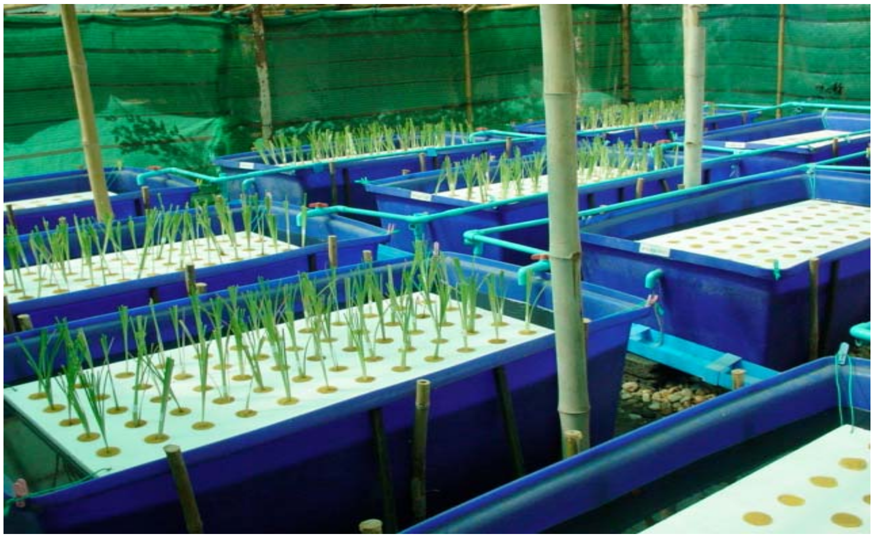

Figure 2 The experimental sets at the starting period under temporary greenhouse

RESULTS AND DISCUSSION:

Influent Water Quality

The characteristics of two different influent strengths are shown in Table 1. The average DO concentrations of both HCW (high concentration wastewater) and LCW (low concentration wastewater) were 0.00 mg/l. The average TKN concentration of HCW was 41.025-52.806 mg/l, primarily NH_4-N 28.000-32.288 mg/l. Other form of N present was NO_3-N 0.020-0.071 mg/l. The average TP concentration of HCW was 5-892-6.657, which 3.911-4.587 mg/l was ortho-PO_4. The average BOD was 90.12-94.97 mg/l.

The average concentrations of TKN, NH_4-N and NO_3-N of LCW were 34.731-42.144, 30.345-35.032 and 0.023-0.045 mg/l, respectively. The average concentrations of TP and ortho-PO_4 were 4.838-5.482 and 3.536-4.097 mg/l, respectively. The average BOD was 44.28-58.97 mg/l. It is obvious that the TKN, TP, ortho-PO_4 and BOD of LCW were significantly lower than HCW ($p<0.05$). In contrast, the concentrations of NH_4-N and NO_3-N of LCW were generally higher than HCW. This may be the result of low BOD concentration in LCW. Thus, at the earlier stage, the supply of DO was still available for ammonification and nitrification processes, resulting in increased of NH_4-N and NO_3-N concentrations.

Table 1 Average influent characteristics

Detention time	Conc.	pH	Cond. (mS/cm)	Temp (°C)	DO (mg/l)	BOD (mg/l)	TKN (mg/l)	NH_4-N (mg/l)	NO_3-N mg/l)	TP (mg/l)	Ortho-PO_4 (mg/l)
7 days	HCW	^{a}7.36 + [illegible]^{a}	^{b}0.81 + [illegible]^{a}	27.97 + [illegible]^{b}	0.00 + [illegible]	^{a}90.12 + [illegible]	^{a}52.806 + [illegible]	^{b}32.28 + [illegible]	^{a}0.071 + [illegible]	^{a}6.657 + [illegible]	^{a}3.911 + [illegible]
	LCW	^{b}7.24 + [illegible]^{a}	^{a}0.87 + [illegible]^{a}	28.10 + [illegible]^{b}	0.00 + [illegible]	^{b}44.28 + [illegible]^{c}	^{b}42.144 + [illegible]	^{a}35.024 + [illegible]	^{b}0.045 + [illegible]	^{b}4.838 + [illegible]	^{b}3.536 + [illegible]
5 days	HCW	7.05 + [illegible]^{b}	^{b}0.76 + [illegible]^{b}	29.42 + [illegible]^{a}	0.00 + [illegible]	^{a}94.88 + [illegible]	^{a}42.813 + [illegible]	^{b}28.343 + [illegible]	0.025 + [illegible]	^{a}6.547 + [illegible]	^{a}4.587 + [illegible]
	LCW	6.93 + [illegible]^{b}	^{a}0.80 + [illegible]^{b}	29.59 + [illegible]^{a}	0.00 + [illegible]	^{b}58.97 + [illegible]^{a}	^{b}36.244 + [illegible]	^{a}31.063 + [illegible]	0.029 + [illegible]	^{b}5.482 + [illegible]	^{b}4.097 + [illegible]
3 days	HCW	7.09 + [illegible]^{b}	^{b}0.76 + [illegible]^{b}	29.59 + [illegible]^{a}	0.00 + [illegible]	^{a}94.97 + [illegible]	^{a}41.025 + [illegible]	^{b}28.000 + [illegible]	^{b}0.020 + [illegible]	^{a}5.892 + [illegible]	^{a}4.407 + [illegible]
	LCW	7.01 + [illegible]^{b}	^{a}0.81 + [illegible]^{b}	29.65 + [illegible]^{a}	0.00 + [illegible]	^{b}51.28 + [illegible]^{b}	^{b}34.731+ [illegible]	^{a}30.345 + [illegible]	^{a}0.023 + [illegible]	^{b}5.060 + [illegible]	^{b}4.082 + [illegible]

Notes: Mean and standard deviation values from 16 replicates are shown.
Superscript letters (left horizontal) denote the significant difference among wastewater concentrations at p=0.05.
Superscript letters (right horizontal) denote the significant difference among detention times at p=0.05.

Change in Water Quality after Treatment

pH, Temperature and Dissolved Oxygen (DO)

The pH is a major factor influencing the availability of nutrients to plants. pH affects the solubility of PO_4-P. The mechanisms by which ions are absorbed by root are pH dependent. Activities of nitrifying bacteria are also influenced by pH. The influent pH was ranging from 6.93-7.36 and the effluent pH was 7.01-7.28 (Table 2). Generally, the effluent pH was higher than the influent and the values became nearly neutral. Moreover, the effluent pH of the experiment sets planted with vetivers were slightly lower than the control set (without plant) which may partially due to the higher organic decomposition rate (which could be observed by the higher BOD removal efficiencies) resulted in CO_2 and acid production which finally lower the effluent pH.

Table 2 Average influent and effluent pH and DO

Detention time	Conc.	Influent pH	Effluent pH			Influent (mg/l)	Effluent DO (mg/l)		
			Songkh	Surat	Control		Songkh	Surat	Control
7 days	HCW	^{a}7.36 +0.11^{a}	7.14 + 0.16	7.11 + 0.16	7.20 + 0.11	0.00 + 0.00	3.88 + 0.88	^{b}3.57 + 0.90	4.08 + 1.25
	LCW	^{b}7.24 +0.66^{a}	7.09 + 0.24	7.09 + 0.19	7.16 + 0.16	0.00 + 0.00	4.12 + 0.89	^{a}4.76 + 1.05	4.68 + 1.32
5 days	HCW	7.05 +0.19^{b}	7.15 + 0.31	7.17 + 0.29	7.28 + 0.19	0.00 + 0.00	2.88 + 1.55	2.29 + 1.15	2.34 + 1.06
	LCW	6.93 +0.17^{b}	7.14 + 0.30	7.18 + 0.20	7.26 + 0.22	0.00 + 0.00	2.47 + 1.09	2.22 + 1.12	2.28 + 1.37
3 days	HCW	7.09 +0.15^{b}	7.11 + 0.08	7.13 + 0.08	7.14 + 0.06	0.00 + 0.00	1.30 + 0.82	1.34 + 0.50	0.96 + 0.62

	LCW	7.01 ±0.10^{b}	7.13 ± 0.11	7.15 ± 0.09	7.16 ± 0.09	0.00 ± 0.00	1.68 ± 0.92	1.60 ± 0.80	1.45 ± 0.76

Notes: Mean and standard deviation values from 16 replicates are shown.
Superscript letters (left horizontal) denote the significant difference among wastewater concentrations at p=0.05.
Superscript letters (right horizontal) denote the significant difference among vetiver ecotypes at p=0.05.
Thai superscript letters (left downward) denote the significant difference among detention times at p=0.05.

Temperature controls the plant growth and development through its influence on the rate of physiological processes. The influent temperature during the experimental period varied between 27.97-29.65 °C.

The average effluent DO concentrations increased significantly from 0.00 to 0.96-4.76 mg/l (Table 2). This rising of DO should be due to aeration by wind, photosynthesis of algae and translocation through the root system of vetivers. Vetivers have free gas exchange with the atmosphere through leaves and stems extending above water and have large gas vessels which conduct gases to the roots. However, the excess oxygen transmitted by plant to root zone is normally consumed by microorganisms and would not contribute significantly to oxygen level in the water (Reed et al., 1988). On the other hand, oxygen leakages from roots stimulate both aerobic decomposition of organic matter and growth of nitrifying bacteria (Brix, 1994). The effluent DO concentrations of 7-, 5- and 3-day detention times were significantly different, ranging from 3.57-4.76, 2.22-2.88 and 0.96-1.68 mg/l, respectively. During the 3-day detention time phase, the effluent DO concentrations of experimental sets planted with Songkhla3 and Surat Thani were higher than control sets. Whereas during the 7-day detention time phase, the control sets showed higher effluent DO. This indicated that the main factor influenced the rising of DO during the limit detention time was vetivers. Whereas the aeration by wind and algal photosynthesis should be the main factors during long detention time resulted in much higher DO concentration and higher DO in control sets which have no plant to inhibit wind and sunlight to penetrate to water column. Generally, the effluent DO concentration in HCW system (0.96-4.08 mg/l) was lower than LCW (1.45-4.76 mg/l) since the available DO in HCW system may be consumed in aerobic decomposition of organic matter.

BOD Removal

Generally, BOD could be removed by settling of particulate BOD and utilization of degradable carbon compound during metabolic process (Reddy and D'Angello, 1997). The average effluent BOD concentrations were ranging from 7.06-27.15 mg/l. The average BOD removal efficiency of 7-day detention time was significantly higher than 5- and 3-day detention times, ranging from 79.91-91.46, 68.95-83.62 and 48.39-77.42%, respectively. The longer detention time yielded higher DO concentration which resulted in high aerobic decomposition rate of organic matter. The removal efficiency of HCW system was significantly higher than LCW, ranging from 76.95-91.46 and 71.15-91.46%, respectively (Table 3).

When comparing different vetiver ecotypes, the results showed that generally Surat Thani yield higher BOD removal efficiency than Songkhla3 with the values of 66.54-91.46 and 54.49-90.54% respectively. Moreover, experiment sets planted with vetivers had higher BOD removal efficiency than the control sets especially during the 5- and 3-day detention times phases. This obviously indicated the beneficial effect of vetiver.

Statistical analysis revealed that the combined effects of detention times and wastewater concentrations caused significant difference on BOD treatment efficiency. The optimal condition for highest BOD removal should be designed at 7- day detention time and high BOD concentration (approximately 90-95 mg/l).

Table 3 Average BOD concentrations and removal efficiencies

Detention time	Conc.	Influent (mg/l)	Effluent (mg/l)			Efficiencies (%)		
			Songkhla3	Surat Thani	Control	Songkhla3	Surat Thani	Control
7 days	HCW	[a]90.12 ± 1.28	7.91 ± 3.53	7.06 ± 3.73	7.20 ± 3.72	[a]90.54 ± 5.44	[a]91.46 ± 5.56	[a]91.38 ± 5.13
	LCW	[b]44.28 ± 6.78	7.98 ± 3.56	7.18 ± 3.12	8.72 ± 4.81	[b]81.56 ± 8.60	[b]83.45 ± 7.16	[b]79.91 ± 10.91
5 days	HCW	[a]94.88 ± 12.63	15.38 ± 7.08	[a]20.66 ± 6.53	21.23 ± 6.73	[a]83.62 ± 7.63[a]	78.00 ± 7.14[b]	[a]77.42 ± 6.95[b]
	LCW	[b]58.97 ± 6.02	15.65 ± 7.84	[b]15.28 ± 5.96	18.38 ± 5.93	[b]73.55 ± 12.62	74.08 ± 9.63	[b]68.95 ± 9.01
3 days	HCW	[a]94.97 ± 11.42	21.62 ± 10.26	21.34 ± 11.6	27.15 ± 12.26	[a]76.95 ± 11.32	[a]77.42 ± 11.85	[a]71.15 ± 12.73
	LCW	[b]51.28 ± 4.99	22.53 ± 10.65[b]	16.76 ± 5.39[c]	25.75 ± 9.50[a]	54.49 ± 24.45[ab]	66.54 ± 12.57[a]	48.39 ± 21.91[b]

Notes: Mean and standard deviation values from 16 replicates are shown.
Superscript letters (right horizontal) denote the significant difference among vetiver ecotypes at p=0.05.
Superscript letters (left downward) denote the significant difference among wastewater concentrations at p=0.05.
Thai superscript letters (left downward) denote the significant difference among detention times at p=0.05.

Nitrogen Removal

Generally organic nitrogen is mineralized to NH_4-N (ammonification process) which may then be nitrified to NO_3-N (nitrification process) if oxygen supply is available. NO_3-N will diffuse to anaerobic zone, then undergoes denitrification process resulting in N_2 and N_2O released to the atmosphere (Gray et al., 2000). In addition, NH_4-N and NO_3-N are uptaked by plants and biota. NH_4-N can be lost to the atmosphere via volatilization especially when pH value is higher than 7.

The effluent TKN and NH_4-N concentrations were ranging from 18.675-31.219 and 14.210-26.499 mg/l, respectively; and the average removal efficiencies were 9.97-62.48 and 13.35-58.62%, respectively (Table 4). When comparing between two vetiver ecotypes, the results showed that TKN removal efficiencies of Songkhla3 and Surat Thani ecotypes were similar. But for NH_4-N removal efficiencies, Songkhla3 posted slightly higher efficiency than Surat Thani. Moreover, the efficiencies of experiment sets planted with vetivers were obviously higher than the control sets, especially during 5- and 3-day detention times. This fact indicated that if the limit detention time was applied, planting with vetivers would be very beneficial since oxygen leakage from roots could promote nitrification process. Moreover, NH_4-N and NO_3-N could be uptake by vetivers.

The average removal efficiencies of at 7-, 5- and 3-day detention times were 52.35-62.48, 28.75-48.89 and 9.97-31.73% respectively for TKN; and were 50.22-58.62, 26.46-55.41 and 11.60-17.69% respectively for NH_4-N. When comparing among different detention times, the removal efficiencies of TKN and NH_4-N significantly increased with detention times. This may probably due to the longer detention time resulted in higher DO (which enhanced ammonification and nitrification processes), higher ammonium volatilization and higher absorption of NH_4-N and NO_3-N by plants and biota.

Table 4 Average influent and effluent nutrient concentrations

Detention	Conc.	Influent (mg/l)	Effluent (mg/l)			Efficiencies (%)		
			Songkhla	Surat	Control	Songkhla	Surat	Control
TKN								
7 days	**HC**	[a]52.806 ±	19.831 ±	19.094 ±	19.213 ±	61.01 ±	62.48 ±	62.29 ±
	LCW	[b]42.144 ±	18.675 ±	19.319 ±	19.506 ±	54.53 ±	52.99 ±	52.35 ±
5 days	**HC**	[a]42.813 ±	21.775±3	23.225 ±	25.506 ±	48.89 ±	[a]45.45 ±	[a]40.22 ±
	LCW	[b]36.244 ±	22.019±5	24.213 ±	26.156 ±	38.47 ±	[b]32.50 ±	[b]28.75 ±
3 days	**HC**	[a]41.025 ±	[b]28.036±	[b]27.994 ±	[b]29.188 ±	[a]31.62 ±	[a]31.73 ±	[a]28.82 ±
	LCW	[b]34.731 ±	[a]30.320±	[a]29.563 ±	[a]31.219 ±	[b]12.56 ±	[b]14.70 ±	[b]9.97 ±
NH_4-N								
7 days	**HC**	[b]32.288 ±	15.645 ±	14.298 ±	14.368 ±	50.22 ±	54.42 ±	54.16 ±
	LCW	[a]35.024 ±	14.210 ±	15.208 ±	15.339 ±	58.62 ±	55.93 ±	55.41 ±
5 days	**HC**	[b]28.343 ±	17.728 ±	19.303 ±	20.528 ±	36.52 ±	30.91 ±	26.46 ±
	LCW	[a]31.063 ±	18.095 ±	20.773 ±	21.543 ±	41.48 ±	32.86 ±	30.34 ±
3 days	**HC**	[b]28.000 ±	[b]22.944 ±	[b]24.206 ±	[b]24.665 ±	17.69 ±	13.35 ±	11.60 ±
	LCW	[a]30.345 ±	[a]25.928 ±	[a]25.401 ±	[a]26.499 ±	14.41 ±	16.02 ±	12.46 ±
NO_3-N								
7 days	**HC**	[a]0.071 ±	0.332 ±	0.383 ±	0.420 ±	nc.	nc.	nc.
	LCW	[b]0.045 ±	0.410 ±	0.359 ±	0.426 ±	nc.	nc.	nc.
5 days	**HC**	0.025 ±	0.580 ±	0.425 ±	0.704 ±	nc.	nc.	nc.
	LCW	0.029 ±	0.475 ±	0.405 ±	0.708 ±	nc.	nc.	nc.
3 days	**HC**	[b]0.020 ±	0.063 ±	0.061 ±	0.074 ±	nc.	nc.	nc.
	LCW	[a]0.023 ±	0.069 ±	0.070 ±	0.079 ±	nc.	nc.	nc.
TP								
7 days	**HC**	[a]6.657 ±	4.276 ±	4.239 ±	[a]5.455 ±	[a]35.32 ±	[a]35.87 ±	[a]17.78 ±
	LCW	[b]4.838 ±	4.056 ±	4.065 ±	[b]4.429 ±	[b]16.13 ±	[b]16.01 ±	[b]8.47 ±
5 days	**HC**	[a]6.547 ±	5.293 ±	5.149 ±	5.895 ±	18.84 ±	21.18 ±	[a]10.14 ±
	LCW	[b]5.482 ±	4.618 ±	4.465 ±	5.081 ±	15.61 ±	18.25 ±	[b]7.23 ±
3 days	**HC**	[a]5.892 ±	4.828 ±	[a]4.707 ±	[a]5.314 ±	[a]18.01 ±	[a]20.29 ±	[a]9.84 ±
	LCW	[b]5.060 ±	4.539 ±	[b]4.330 ±	[b]4.735 ±	[b]10.04 ±	[b]14.15 ±	[b]6.30±
Ortho-PO_4								
7 days	**HC**	[a]3.911 ±	[a]3.129 ±	2.989 ±	3.249 ±	[a]19.81 ±	[a]23.46 ±	[a]15.40 ±
	LCW	[b]3.536 ±	[b]2.991 ±	2.976 ±	3.305 ±	[b]15.37 ±	[b]15.77 ±	[b]8.05 ±

5 days	**HC**	[a]4.587 ±	[a]3.816 ±	3.605 ±	[a]4.037 ±	16.70 ±	[a]21.22 ±	11.91±
	LCW	[b]4.097 ±	[b]3.499 ±	3.464 ±	[b]3.651 ±	13.94 ±	[b]14.81 ±	10.57 ±
3 days	**HC**	[a]4.407 ±	3.686 ±	3.469 ±	3.885 ±	[a]15.85 ±	[a]19.32 ±	11.46 ±
	LCW	[b]4.082 ±	3.700 ±	3.572 ±	3.826 ±	[b]9.67 ±	[b]13.46 ±	7.40 ±

Notes: Mean and standard deviation values from 16 replicates are shown.
Superscript letters (right horizontal) denote the significant difference among vetiver ecotypes at p=0.05.
Superscript letters (left downward) denote the significant difference among wastewater concentrations at p=0.05.
Thai superscript letters (left downward) denote the significant difference among detention times at p=0.05.
nc. = not calculated

When comparing between different wastewater concentrations, the removal efficiencies of TKN in HCW system was significantly higher than LCW system but the removal efficiencies of NH_4-N in LCW was generally higher than HCW system. This was due to the LCW contained higher NH_4-N but lower BOD concentrations than HCW. After passing through the systems, the LCW yielded higher DO than HCW since small amount of DO was consumed for aerobic decomposition of organic matter. Thus, the DO was available for ammonification and/ or nitrification processes.

Statistical analysis revealed that the combined effects of vetiver ecotypes, detention times and wastewater concentrations did not cause any significant difference on treatment efficiencies of NH_4-N and NO_3-N.

In contrast to TKN and NH_4-N concentrations, the effluent NO_3-N concentration was higher than the influent and highly varied, ranging from 0.061-0.708 mg/l. This suggested that the rising of DO concentration in the systems promoted the nitrification process resulted in higher NO_3-N concentration and lower NH_4-N concentration. It should be noted that the effluent from the experiment sets planted with vetivers (0.061-0.580 mg/l) was lower than control sets (0.074-0.708 mg/l). This indicated that vetivers could absorp NO_3-N but the quantity may be low because of the small size of vetivers. In addition, generally effluent NO_3-N from Surat Thani sets was lower than Songkhla3 sets which showed that Surat Thani ecotype had high potential in NO_3-N uptake.

Phosphorus Removal

Generally, phosphorus in wastewater may be removed through sedimentation and burial, adsorption and precipitation, and exchange process between soil and overlying water column. However, the hydroponic technique (without soil) that was used in this experiment yielded low phosphorus removal efficiency compared to other studies. The average TP and ortho-PO_4 removal efficiencies were ranging from 6.30-35.87 and 7.40-23.46%, respectively (Table 4).

When comparing between two vetiver ecotypes, the results showed that TP and ortho-PO_4 removal efficiencies of Songkhla3 and Surat Thani ecotypes were similar. But Surat Thani ecotype tended to yield slightly higher efficiencies. Moreover, the efficiencies of experiment sets planted with vetivers were significantly higher than control sets since they could absorp ortho-PO_4 and their roots could slow water velocity, thus increased sedimentation of organic phosphorus.

The average removal efficiencies of during 7-, 5- and 3-day detention times were 8.47-35.87, 7.21-21.18 and 6.30-20.29% respectively for TP; and were 8.47-35.87, 7.21-21.18 and 6.30-20.29%, respectively for ortho-PO_4. When comparing among different detention times, the removal efficiencies significantly increased with detention times. Futhermore, when comparing between different wastewater concentrations, the removal efficiencies in HCW system were significantly higher than LCW system.

Statistical analysis revealed that the combined effects of vetiver ecotypes, detention times and wastewater concentration did not cause any significant difference on treatment efficiencies of ortho-PO_4. However, the combined effects of detention times and wastewater concentrations, detention times and vetiver ecotypes; and wastewater concentrations and vetiver ecotypes caused significant difference on treatment efficiencies of TP. The optimal condition for highest TP removal should be designed at 7- day detention time and high TP concentration (approximately 6-7 mg/l) and planted with Surat Thani ecotype.

Growth, Biomass and Nutrient Accumulation of Vetivers

After 8 weeks of experiment, the survival percentages of Surat Thani and Songkhla3 ecotypes were ranging from 75-100%. The survival percentage during 3-day detention time was lower than 7- and 5-day detention time. This may be the result of low oxygen available, thus, resulting in retarding respiration and ion absorption of vetivers. Moreover, the survival percentage of vetivers planted in LCW tended to be slightly higher than in HCW (Table 5).

Table 5 Survival rate and growth of shoots and roots of vetivers

Detention time	**Ecotypes**	**Conc.**	**%**	**% New produce**	**% New produce**	**Avg. height**	**Avg. new length**
7 days	**Songkhla 3**	**HCW**	91.67	35.00	100.00	69.23 ±	10.84 ±
		LCW	91.67	31.67	100.00	71.83 ±	11.44 ±
	Surat Thani	**HCW**	91.67	35.00	100.00	^{b}62.36 ±	10.21 ±
		LCW	93.33	28.33	100.00	^{a}78.03 ±	11.90 ±
5 days	**Songkhla 3**	**HCW**	95.00	48.33	100.00	^{b}76.66 ±	11.39 ±
		LCW	100.00	46.67	100.00	^{a}100.91±	11.10 ±
	Surat Thani	**HCW**	88.33	25.00	100.00	81.40 ±	10.72 ±
		LCW	98.33	45.00	100.00	92.10 ±	12.89 ±
3 days	**Songkhla 3**	**HCW**	80.00	20.00	83.33	58.82 ±	7.23 ±
		LCW	75.00	18.33	76.67	56.43 ±	6.59 ±
	Surat Thani	**HCW**	83.33	18.33	78.33	62.72 ±	8.26 ±
		LCW	91.67	20.00	85.00	76.12 ±	6.83 ±

Notes: Superscript letters (right downward) denote the significant difference among vetiver ecotypes at p=0.05.
Superscript letters (left downward) denote the significant difference among wastewater concentrations at p=0.05.
Thai superscript letters (right downward) denote the significant difference among detention times at p=0.05.

According to the percentages of vetivers which produced new shoots and new roots; and length of roots and shoots, it was found the similar trend as survival percentage, i.e. the values during 3-day detention time was lower than 7- and 5-day detention time. Songkhla3 ecotype planted in HCW tended to have those parameters (except shoot height) higher than in LCW.

On the contrary, Surat Thani ecotype planted in LCW showed higher values than in HCW. According to shoot height, both Songkhla3 and Surat Thani eotypes planted in LCW showed slightly higher values than in HCW. This should be due to LCW contained higher NH_4-N and NO_3-N concentrations, which were macronutrients needed for stem and leaf development (Parker, 2000).

According to biomass increment of shoot and roots, the values were lowest during the 3-day detention time and highest during 7-day detention time (Table 6). There was a tendency that Surat Thani ecotype planted in both HCW and LCW had higher increment of root biomass than Songkhla3. This indicated that Surat Thani ecotype could develop better root system. Thus, higher amounts of PO_4-P which was macronutrient needed for root development were required. As a result, higher TP and PO_4-P treatment efficiencies were achieved as mentioned previously.

When comparing between Songkhla3 and Surat Thani ecotypes, it was found that Songkhla3 planted in HCW tended to have higher shoot biomass than Surat Thani and than those planted in LCW. On the other hand, Surat Thani planted in LWC showed higher shoot and root biomass. However, both vetiver ecotypes could develop good growth in both wastewater strengths.

Table 6 Shoot and root biomass of vetivers

Detention	Ecotypes	Conc.	Shoot biomass			Root biomass		
			Before	After (g)		Before	After (g)	
7 days	Songkhla3	HC	1.13 ±	*3.60 ±	231.79 ±	0.35 ±	*0.72 ±	112.50 ±
		LC	1.13 ±	*3.32 ±	209.60 ±	0.35 ±	*0.71 ±	106.64 ±
	Surat Thani	HC	0.99 ±	^{*b}2.66 ±	^{b}175.99 ±	0.28 ±	*0.58 ±	114.04 ±
		LC	0.99 ±	^{*a}3.00 ±	^{a}215.16 ±	0.28 ±	*0.56 ±	110.34 ±
5 days	Songkhla3	HC	1.60 ±	^{*b}2.91 ±	^{b}82.05 ±	0.53 ±	*0.86 ±	63.53 ±
		LC	1.60 ±	^{*a}3.32 ±	^{a}107.43 ±	0.53 ±	*0.87 ±	65.24 ±
	Surat Thani	HC	1.37 ±	^{*b}2.78 ±	^{b}102.78 ±	0.38 ±	*0.73 ±	89.66 ±
		LC	1.37 ±	^{*a}3.87 ±	^{a}182.38 ±	0.38 ±	*0.86 ±	123.78 ±
3 days	Songkhla3	HC	1.60 ±	*2.54 ±	58.46 ±	0.38 ±	^{*a}0.63 ±	^{a}65.86 ±
		LC	1.60 ±	*2.36 ±	47.06 ±	0.38 ±	^{*b}0.52 ±	^{b}37.23 ±
	Surat Thani	HC	1.79 ±	^{*b}2.39 ±	^{b}33.53 ±	0.42 ±	*0.70 ±	68.14 ±
		LC	1.79 ±	^{*a}2.97 ±	^{a}66.01 ±	0.42 ±	*0.81 ±	93.86 ±

Notes: Mean and standard deviation values from 30 replicates are shown.
Superscript letters (right downward) denote the significant difference among vetiver ecotypes at p=0.05.
Superscript letters (left downward) denote the significant difference among wastewater concentrations at p=0.05.
Thai superscript letters (right downward) denote the significant difference among detention times at p=0.05.
* Right horizontal denote the significant difference between before and after experiment at p=0.05.

The TN accumulation in shoots of Songkhla3 and Surat Thani were 1.785-8.400 and 2.765-5.985 mg/d dry wt., respectively and the accumulation in roots were 2.240-10.045 and 6.860-8.133 mg/d dry wt., respectively (Table 7). It was obvious that TN accumulation in roots was higher than shoots. The result from this study was opposite to the study of Taneeya

Jetinukornkul (1996) that found TN accumulation in shoots was higher than roots. This may due to the size of vetivers in this study was small. As a result, small amount of TN was needed for the growth of stems and leaves.

When comparing between vetiver ecotypes, Songkhla3 planted in HCW showed higher TN accumulation in shoots and roots than Surat Thani. In contrast, Surat Thani planted in LCW showed higher accumulation than Songkhla3.

The TP accumulation in shoots of Songkhla3 and Surat Thani were 0.493-1.993 and 1.217-2.422 mg/d dry wt., respectively and the accumulation in roots were 0.530-2.164 and 1.088-2.906 mg/d dry wt., respectively. It was obvious that TP accumulation in roots was higher than accumulation in shoots.

Table 7 Average nutrient accumulation in shoots and roots

Detention time	Ecotypes	Conc	Shoots (mg/g dry wt)			Roots (mg/g dry wt)		
			Before	After	Increment	Before	After	Increment
TN								
7 days	Songkhla3	HCW	5.460 ± 0.099[b]—	[*a]9.065 ± 0.148	[a]3.605 ± 0.148	5.600 ± 0.594	15.645 ± 4.900	10.045 ± 4.900
		LCW	5.460 ± 0.099[b]—	[*b]7.245 ± 0.544	[b]1.785 ± 0.544	5.600 ± 0.594	[*]13.265 ± 0.247–	7.665 ± 0.247–
	Surat Thani	HCW	7.735 ± 0.049[a]	10.675 ±1.237	2.940 ± 1.237	6.147 ± 0.217	[*]14.280 ± 1.386	8.133 ± 1.386
		LCW	7.735 ± 0.049[a]	10.500 ± 1.485	2.765 ± 1.485	6.147 ± 0.217	[*]14.140 ± 1.980	7.993 ± 1.980
5 days	Songkhla3	HCW	5.005 ± 0.247–	[*]13.405 ± 2.425	8.400 ± 2.425	5.530 ± 0.297	[*]14.420 ± 2.376	8.890 ± 2.376
		LCW	5.005 ± 0.247–	11.900 ± 2.277	6.895 ± 2.277	5.530 ± 0.297	[*]12.740 ± 0.099–	7.210 ± 0.099–
	Surat Thani	HCW	4.725 ± 1.039	10.710 ± 0.198	5.985 ± 0.198	5.075 ± 0.247	[*]13.055 ± 0.544	7.980 ± 0.544
		LCW	4.725 ± 1.039	9.765 ± 1.435	5.040 ± 1.435	5.075 ± 0.247	[*]12.180 ± 0.693	7.105 ± 0.693
3 days	Songkhla3	HCW	6.300 ± 0.396–	10.710 ± 1.881	4.410 ± 1.881	5.110 ± 0.495	[*]8.785 ± 0.940	3.675 ± 0.940
		LCW	6.300 ± 0.396–	9.555 ± 2.821	3.255 ± 2.821	5.110 ± 0.495	7.350 ± 0.693–	2.240 ± 0.693–
	Surat Thani	HCW	5.810 ± 0.693	8.785 ± 2.326	2.975 ± 2.326	4.340 ± 0.792	[*]9.940 ± 1.287	5.600 ± 1.287
		LCW	5.810 ± 0.693	11.200 ± 2.178	5.390 ± 2.178	4.340 ± 0.792	11.200 ± 2.475	6.860 ± 2.475
TP								

7 days	**Songkhla3**	**HCW**	2.128 ± 0.254	*3.058 ± 0.111	0.877 ± 0.111^{b}	1.259 ± 0.137	3.423 ± 0.874	2.164 ± 0.875
		LCW	2.128 ± 0.254	*3.252 ± 0.059	1.070 ± 0.059	1.259 ± 0.137	*2.661 ± 0.033	1.403 ± 0.033^{b}
	Surat Thani	**HCW**	1.587 ± 0.104	*3.280 ± 0.215	1.693± 0.216^{a}	0.904 ± 0.287	*3.810 ± 0.796	2.906 ± 0.796
		LCW	1.587 ± 0.104	*2.804 ± 0.287	1.217 ± 0.287	0.904 ± 0.287	*3.132 ± 0.241	2.228 ± 0.242^{a}
5 days	**Songkhla3**	**HCW**	2.648 ± 0.039^{a}	3.141 ± 0.476	0.493 ± 0.477^{b}	1.065 ± 0.007^{a}	*2.394 ± 0.124	1.329 ± 0.124
		LCW	2.648 ± 0.039^{a}	3.459 ± 0.561	0.812 ± 0.561	1.065 ± 0.007^{a}	*1.808 ± 0.170	0.743 ± 0.170
	Surat Thani	**HCW**	1.268 ± 0.189^{b}	*3.556 ± 0.202	2.288 ± 0.202^{a}	0.530 ± 0.007^{b}	*1.863 ± 0.339	1.334 ± 0.339
		LCW	1.268 ± 0.189^{b}	*3.690 ± 0.613	2.422 ± 0.614	0.530 ± 0.007^{b}	*2.108 ± 0.294	1.578 ± 0.293
3 days	**Songkhla3**	**HCW**	1.213 ± 0.202	*3.206 ± 0.111	1.993 ± 0.111^{a}	0.909 ± 0.098^{a}	1.725 ± 0.509	0.816 ± 0.509
		LCW	1.213 ± 0.202	2.592 ± 0.470	1.379 ± 0.470	0.909 ± 0.098^{a}	*1.439 ± 0.052^{b}	0.530 ± 0.052^{b}
	Surat Thani	**HCW**	1.310 ± 0.091	*2.671 ± 0.150	1.361 ± 0.150^{b}	0.554 ± 0.026^{b}	*1.734 ± 0.313	1.181 ± 0.313
		LCW	1.310 ± 0.091	*2.989 ± 0.509	1.679 ± 0.509	0.554 ± 0.026^{b}	*1.642 ± 0.039^{a}	1.088 ± 0.040^{a}

Notes: Superscript letters (right downward) denote the significant difference among vetiver ecotypes at p=0.05.
Superscript letters (left downward) denote the significant difference among wastewater concentrations at p=0.05.
Thai superscript letters (right downward) denote the significant difference among detention times at p=0.05.
* Right horizontal denote the significant difference between before and after experiment at p=0.05.

When comparing the TP accumulation in shoots and roots between vetiver ecotypes, generally Surat Thani ecotype yielded higher values than Songkhla3. This result correlated to higher TP and ortho-PO_4 treatment efficiencies of Surat Thani than Songkhla3.

When comparing between detention time, the TN and TP accumulations in roots during 7-day detention time was higher than 3- and 5-day, respectively. But no obvious trend was observed in TN and TP accumulations in shoots.

CONCLUSIONS:

The results from this present study using hydroponic technique indicated that even treatment efficiencies of nitrogen and phosphorus were low compare to other studies which had soils as media, vetivers had showed a good potential to be used in situ to treat domestic wastewater. Therefore, use of vetivers culivated with floating platform for domestic wastewater treatment is applicable.

The 7-day detention time posted highest treatment efficiencies. The treatment efficiencies of BOD, TKN, TP, ortho-PO_4 and NH_4-N increased with concentrations which indicated high potential of vetiver to treat HCW. In addition, the treatment efficiencies of BOD, TP and ortho-PO_4 of Surat Thani ecotype were slightly higher than Songkhla3 ecotype. The results closely correlated with the study of growth which found that Surat Thani could develop better root system than Songkhla3 in both HCW and LCW. As a results, it absorped higher amount of ortho-PO_4 for root development. The treatment efficiencies of NH_4-N of Songkhla3 was slightly higher than Surat Thani. The results closely correlated with the study of growth which found that Songkhla3 planted in HCW tended to have higher shoot biomass and nitrogen accumulation. In conclusion, the optimal condition of vetivers cultivated with floating platform technique in domestic wastewater treatment should be designed at 7-day detention time and planted with Surat Thani ecotype. However, if wastewater contained high nutrients, Songkhla3 ecotype should be planted instead.

It should be noted that a method to increase available oxygen in the system should be provided. Since it is expected from the results that available oxygen is one factor that limited the treatment efficiencies of nutrients, especially nitrogen; and growth of vetivers. The influence of vetiver biomass on treatment efficiencies should also be investigated intensively.

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A Brief Introduction to the First Author

Kanokporn Boonsong got her PhD. in Natural Resource Conservation, with her background knowledge in Botany and Environmental Science. She is now Assistant Professor at Department of General Science, Faculty of Science, Chulalongkorn University. She had conducted researchs on usage of wetlands especially mangroves to treat domestic wastewater for more than 7 years.