Assessment of Nutrients Removal by Constructed Wetlands Using Reed Grass (Phragmites australis L.) and Vetiver Grass (Vetiveria Zizanioides L.)

KY, Nguyen Minh
Faculty of Environment and Natural Resources, Nong Lam University of Ho Chi Minh City

HUNG, Nguyen Tri Quang
Faculty of Environment and Natural Resources, Nong Lam University of Ho Chi Minh City

MANH, Nguyen Cong
Faculty of Environment and Natural Resources, Nong Lam University of Ho Chi Minh City

LAP, Bui Quoc
Faculty of Chemistry and Environment, Thuyloi University,

他

https://doi.org/10.5109/2558907

出版情報：九州大学大学院農学研究院紀要. 65 (1), pp.149-156, 2020-02. 九州大学大学院農学研究院
バージョン：
権利関係：

J. Fac. Agr., Kyushu Univ., **65** (1), 149–156 (2020)

Assessment of Nutrients Removal by Constructed Wetlands Using Reed Grass (*Phragmites australis* L.) and Vetiver Grass (*Vetiveria Zizanioides* L.)

Nguyen Minh KY[1], Nguyen Tri Quang HUNG[1], Nguyen Cong MANH[1], Bui Quoc LAP[2]*, Huyen Thi Thanh DANG[3] and Akinori OZAKI[4]

Institute of Tropical Agriculture Kyushu University, Fukuoka 819–0395, Japan
(*Received October 31, 2019 and accepted November 14, 2019*)

Constructed wetland (CW) has been considered one of the low cost and effective wastewater treatment technologies for application in Vietnam. This paper attempted to evaluate the nutrient absorption ability of reed grass (*Phragmites australis L.*) and vetiver grass (*Vetiveria Zizanioides L.*) utilized in the vertical flow constructed wetland systems. Different hydraulic loading rates of 500 *ml*/min/m^2, 1000 *ml*/min/m^2 and 1500 *ml*/min/m^2 were tried. The results showed that the nutrient removal percentage was highest at the hydraulic loading rate of 500 *ml*/min/m^2. There was no statistically significant difference in nutrient removal between reed grass and vetiver at the same loading rate ($p>0.05$). Nevertheless, at the same loading level, the nutrient removal of the wetlands with plants was always higher than those without the plants ($p<0.05$). The effluent from the vertical constructed wetlands using plants all met the National technical regulation of surface water quality for agricultural irrigation purposes (column B1 in QCVN 08–MT: 2015/BTNMT). Thus, the constructed wetland using reed grass and vetiver grass would be quite a promising low cost technology for treatment of wastewater for irrigation purpose.

Key words: Hydraulic loading rate, Nutrients removal, *Phragmites australis L.*, Vertical flow constructed wetland, *Vetiveria zizanioides L.*

INTRODUCTION

Vietnam has been now facing with an increasing utilization of untreated wastewater for agricultural irrigation. This has led to increasing number of poisonous food cases and affecting the human health to a severe level. People now prefer growing their vegetables for themselves to buying from the farmers who irrigate their plants with dirty water. It is the limited capacity (budget and human resources) of the local government and high construction and operation costs of a wastewater treatment plant that leaves more than 90% of wastewater from rural areas untreated.

Due to the urbanization and industrialization, a significant amount of the industrial and domestic wastewater was discharged to the environment that threatens surrounding aquatic systems such as canals and irrigation canals in Vietnam. The surface water quality including water quality for irrigation was vulnerable due to the industrial and agricultural activities (Carpenter *et al.*, 1998; Jarvie *et al.*, 1998). Pollution of nutrients affected badly the ecosystems, causing eutrophication in water bodies (Guy *et al.*, 2012; Manuel, 2014; Xinyu *et al.*, 2017). On the other hand, the capacity of irrigation canals is limited, while more and more water is needed for aquaculture activities. Regarding to water in the irrigation systems, it requires the suitable quality standards (Maimon *et al.*, 2010, Travis *et al.*, 2010). In this situation, the question is whether to find the technologies that have the appropriate cost to treat the contaminated waters for agricultural cultivation.

Constructed wetland (CW) technology has been well known as an effective wastewater treatment technology solution (ElZein *et al.*, 2016) with advantages such as low cost of construction and low cost for operation and maintenance (Kadlec and Wallace, 2009). It has been shown to be capable of treating municipal, domestic, industrial, sewage, aquaculture wastewaters, etc. (Dallas *et al.*, 2004; Vymazal, 2009; Katarzyna and Magdalena, 2017). In particular, there have been many applied studies to examine the possibility of reusing the wastewaters for the agricultural irrigation purpose (Farid *et al.*, 2014; Zeshan *et al.*, 2018).

According to Kadlec and Knight (1996), the main kinds of CWs are free water subsurface (FWS) CWs and subsurface flow (SSF) CWs, in which, SSF CWs are further classified into vertical subsurface flow (VSSF) and horizontal subsurface flow (HSSF) systems. The removal efficiencies of FWS CWs were unstable and not so high (<50%) compared to subsurface systems for total suspended solid (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total phosphorous (TP) and total nitrogen (TN) (Zhang *et al.*, 2014). Many previous studies revealed that the performance of constructed wetlands varied with different plant species and their productivities (Zhang *et al.*, 2014). The total nitrogen (TN) and total phosphorous (TP) removal rates were 58.6% and 66.5% for *Typha angustifolia*; 45% and 81.7% for *Thaliade albata*; 52.8% and 40% for *Anthurium andreanum*, respectively; while they were 15% and 52% for *Canna indica*; 23.97% and 30.69% for *Lemna minor*; 25.57% and

[1] Faculty of Environment and Natural Resources, Nong Lam University of Ho Chi Minh City, VIETNAM
[2]* Faculty of Chemistry and Environment, Thuyloi University, 175 Tay Son Street, Dong Da District, Hanoi, VIETNAM. Corresponding author (Email: buiquoclap@tlu.edu.vn)
[3] Faculty of Environmental Engineering, National University of Civil Engineering, Vietnam
[4] Institute of Tropical Agriculture Kyushu University, JAPAN

46.45% for *Azolla pinnata* (Muvea *et al.*, 2019). In particular, vetiver grass was studied and applied to treat different types of polluted water by previous researchers (Roongtanakiat and Chairoj, 2001; Lu *et al.*, 2004; Dudai *et al.*, 2006; Truong *et al.*, 2010; Datta *et al.*, 2013; Seroja *et al.*, 2018). Similarly, the reed grass (*Phragmites australis L.*) was also used as an effective target for the treatment of water pollution and environmental protection (Havens *et al.*, 2003; Abou–Elela *et al.*, 2012; Mirco and Attilio, 2013; Aboubacar *et al.*, 2018).

Therefore, this paper aims at evaluating the application of environmental friendly and low cost technology such as the vertical subsurface (VSS) constructed wetland (CW) for the treatment of wastewater for irrigation. Two kinds of floras, reed grass (*Phragmites australis L.*) and vetiver grass (*Vetiveria Zizanioides L.*), were employed. The impact of hydraulic loading rates was also considered in this study.

MATERIALS AND METHODS

Feed wastewater

The input for this experiment was the contaminated water from the canal D in Thuan An Town, Binh Duong Province as shown in Figure 1. Thuan An town, with a total natural area of 82.46 km^2 and a population of 361,640 people, belongs to the dynamic economic zone in the South of Vietnam.

The canal D receives significant domestic and industrial wastewater from Areco residential area and Dong An Industrial Zone. Water quality of canal D has been heavily polluted by nutrients and organic matters. Monitoring data showed that this water did not meet the quality standard for agricultural irrigation according to Vietnam's national technical regulation for surface water quality (QCVN 08–MT: 2015/BTNMT). Characteristics of the contaminated water used in the experiment, with different loading rates of 500 *ml*/min/m^2 (T1), 1000 *ml*/min/m^2 (T2) and 1500 *ml*/min/m^2 (T3), are shown in Table 1. It can be seen from Table 1 that amonium nitrogen (NH_4–N) was higher than the standard value most of the time, while phosphate (PO_4^{3-}) was occasionally beyond the standard.

Plants used for constructed wetland

Based on the results of previous studies, local availability and relatively high treatment efficiency, *Phragmites australis* and *Vetiverria zizanioides L* were selected for the study (Havens *et al.*, 2003; Danh *et al.*, 2009; Indrayatie *et al.*, 2013; Abou–Elela and Hellal, 2012; Mirco and Attilio, 2013; Effendi *et al.*, 2015;

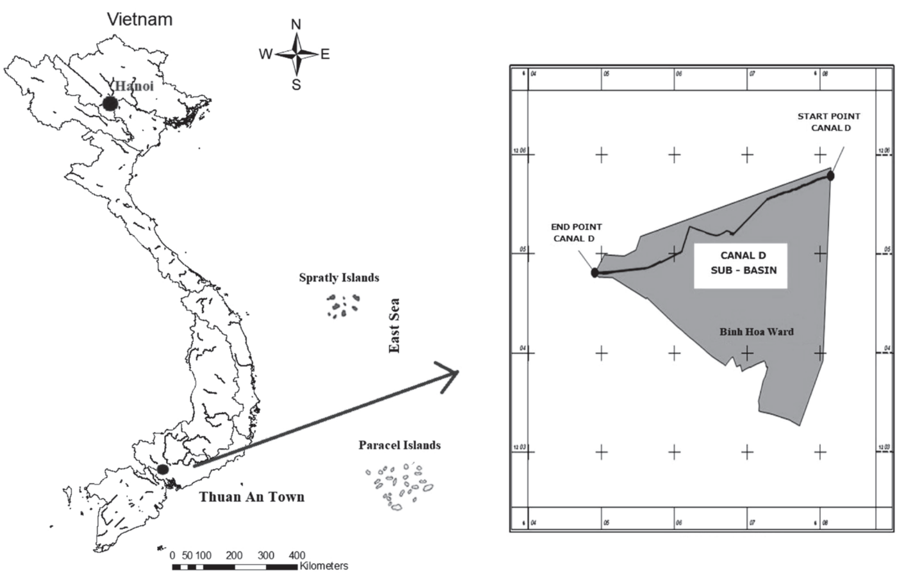

Fig. 1. Location of experimental set up.

Table 1. Characteristics of pre–treated water quality[a]

Load[b]	Parameters, (mg/*l*)					
	TP	PO_4^{3-}	TKN	N–NH_4	N–NO_2	N–NO_3
T1	1.13±0.4	0.06±0.02	50.39±12.2	29.77±2.7	0.01±0.01	0.08±0.03
T2	2.38±0.06	1.41±0.09	33.39±6.19	17.01±6.14	0.02±0.01	0.06±0.04
T3	1.54±0.8	0.19±0.1	27.79±0.38	18.16±0.5	0.05±0.04	0.10±0.05
QCVN 08–MT: 2015 (B1)	N/A	0.3	N/A	0.9	0.05	10

[a] *Average value ± Standard deviation; QCVN 08–MT: 2015/BTNMT: National technical regulation on surface water quality; Column B1 – For irrigation purpose.*

[b] *Hydraulic loading rates: 500 ml/min/m^2 (T1), 1000 ml/min/m^2 (T2) and 1500 ml/min/m^2 (T3)*

Phragmites australis *Vetiverria zizanioides*

Fig. 2. Flora used in the experiement.

Badejo *et al*., 2018; Aboubacar *et al*., 2018). These grasses were quite common in the Aquatic Biological Collection Garden of Nong Lam University of Ho Chi Minh City. The relatively mature grasses with strong stems (0.5 to 1 cm–wide and 40 to 50 cm long) were selected. After that, their leaves were divided into bundles of 4 to 5 stems. Those seeding bundles were planted every 20 cm in distance, with density of 20 plants/m2 in the constructed wetland systems. The experiment was conducted after they have been planted for 5 months – with a growing height of 0.6 to 0.8 m.

Experimental design

The experiment was designed following the factorial experiment approach. Two factors were examined including hydraulic loading rates and the type of plants. In which, the loading rates included 3 levels of 500 *ml*/min/m^2 (T1), 1000 *ml*/min/m^2 (T2) and 1500 *ml*/min/m^2 (T3). In specific, these 3 loading levels (T1, T2, T3) were tested through the VSS constructed wetlands with Reed Grass (S_{T1}, S_{T2}, S_{T3}), Vetiver Grass (V_{T1}, V_{T2}, V_{T3}) and without the plants for the reference (C_{T1}, C_{T2}, C_{T3}). Number of experiments were determined via the randomized complete block design method, a standard design for agricultural experiments in which similar experimental units are grouped into blocks or replicates. Triplicates were conducted in this study (Table 2).

Regarding the layout of the experimental set up, the wastewater from the canal D was pumped into a feed tank, which was placed 1.5 m higher than the surface of the VSS constructed wetland systems. The wastewater was pumped from the tank into the VSS CW systems by quantitative pumps (#72–370–000, MANOSTAT, USA) to control the loading rate and retention time corresponding to the each experiment (Fig. 3).

Each VSS CW system had a volume of 1000 L (1 m × 1 m × 1 m). Fig. 4 depicts clearly its structure, including

Table 2. Experimental design

Load	Reed grass (S)	Vetiver (V)	Reference (C)
T1	S_{T1}	V_{T1}	C_{T1}
T2	S_{T2}	V_{T2}	C_{T2}
T3	S_{T3}	V_{T3}	C_{T3}

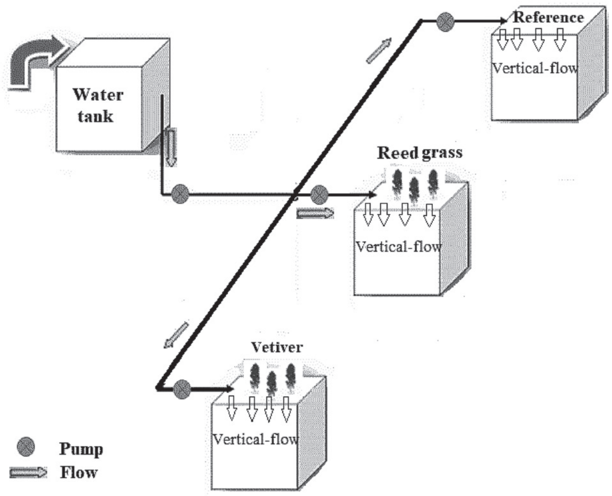

Fig. 3. Diagram of experiment set up.

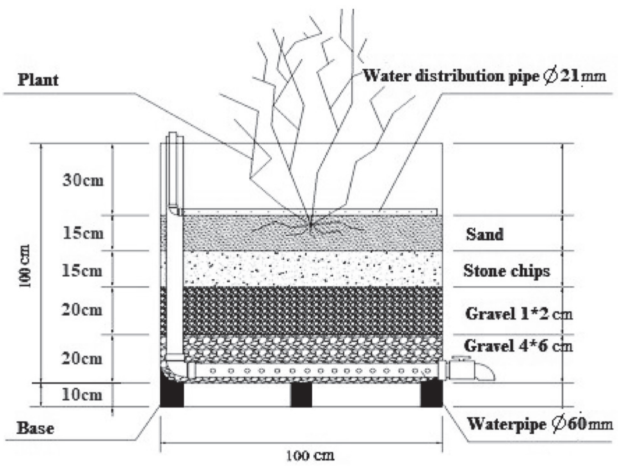

Fig. 4. Cross – section of Vertical subsurface flow constructed wetland system.

a layer of gravel (size 4 cm × 6 cm) with 20 cm thick, second layer of gravel (size 1 cm × 2 cm) with 20 cm thick, a layer of stone chips with 15 cm thick, and top sand grains (ϕ = 1 ÷ 2 mm) with 15 cm thick. The porosity of the whole filter media was 40%. The plants were grown from the top sand. Feed wastewater was provided via a perforated pipe (ϕ = 21 mm) from the top, then it was filtered through medial vertically and collected at the bottom by a water pipe (ϕ = 60 mm). For the reference system, there was no plants on top.

Statistical and analytical methods

The water samples were collected from the inlet and outlet of the VSS CW systems, once per week, for 10 weeks. The samples were analyzed at the Laboratory of Environment Engineering, Center for Environmental Technology and Natural Resource Management, Nong Lam University of Ho Chi Minh City to determine TP, PO_4^{3-}, TKN, NH_4^+–N, NO_2–N and NO_3–N. The analysis of these parameters was complied with the "Standard Methods for the Examination of Water and Wastewater" (APHA, 2012).

The removal efficiencies (H%) of treatment system (reed grass, vetiver and control) were calculated based on the following formula:

$$H\ \% = \{(C_{inf} - C_{eff}) / C_{inf}\} *100$$

In which, C_{inf} is initial concentration and C_{eff} is final concentration of corresponding parameter.

ANOVA analysis was employed to find significantly statistical differences between experiments. All statistical analyses were performed using SPSS 13.0 with significance was $p<0.05$.

RESULTS AND DISCUSSION

Treatment efficiency of VSS CW systems at loading level of 500 *ml*/min/m² (T1)

Fig. 5 shows the pre– and post–treatment concentrations of total phosphorus (TP) and PO_4^{3-} in T1 experiment. The concentrations of TP and PO_4^{3-} before treatment were respectively 1.13 ± 0.39 and 0.06 ± 0.02 mg/*l*. After treatment, there was a clearly decrease in concentrations with floras (V1, S1) and without floras (reference C1). The treatment efficacies of TP and PO_4^{3-} in the reference CW model were 93.4 ± 1.8 and 61.6 ± 29.2%, in the CW model using reed grass were 95.4 ± 1.5 and 54.4 ± 8.5%; and in the CW model using vetiver grass were 95.0 ± 0.7 and 50.1 ± 11.5%, respectively (Fig. 5). The effluent eventually met the national technical regulation on surface water quality, used for agricultural irrigation purposes (QCVN 08–MT: 2015/ BTNMT, Column B1). Overall, the TP removal efficiency was quite high (> 90%).

Despite the removal of phosphorous was substantial, it was not that significant for nitrogen (TKN, NH_4–N) (Fig. 6). Contrary to the decline of TKN and NH_4–N concentrations, the concentrations of (NO_2–N + NO_3–N) increased more than 100 times in both the control and the ones with floras. This proved that nitrogen has well transferred from NH_4–N form to nitrite NO_2 and nitrate NO_3 forms during the oxidation process within the system. Accordingly, the reduction of TKN or TN was observed and the NH_4–N concentration was lower than the standard eventually. The efficiency of TKN treatment by reed grass was 74 ± 17% and 68 ± 21% for NH_4–N; the similar was observed for vetiver grass of 68 ± 16% and 64 ± 15%, respectively. Meanwhile, the corresponding values in the reference CW model were 60 ± 13% and 52 ± 10%. There seems to be a difference in nitrogen removal between the control and the ones with plants.

These treatment results were somewhat comparable with other studies on nutrient removal using vertical flow constructed wetlands (Vymazal *et al.*, 2002; Brix and Arias, 2005; Vymazal *et al.*, 2009; Zurita *et al.*, 2009). For instance, Brix and Arias (2005) found that the NH_4–N treatment efficiency was 78%, TKN was 43% and TP was 25% when using vertical flow wetland system for domestic wastewater treatment in Denmark. This high conversion efficiency was due to the characteristics of vertical subsurface flow within the wetland (Kadlec and Wallace, 2009).

Treatment efficiency of vertical flow model with loading level of 1000 m*l*/min/m² (T2)

Removal results of total phosphorus (TP) and PO_4^{3-} are shown in Fig. 7 for the experiment T2. The concentrations of TP and PO_4^{3-} before treatment were 2.38 ± 0.06 and 1.41 ± 0.09 mg/*l*, respectively. Again, a

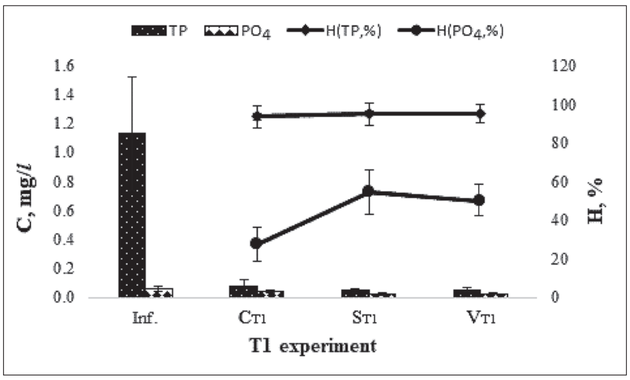

Fig. 5. Phosphous removal efficiency at 500 m*l*/min/m² hydraulic loading rate.

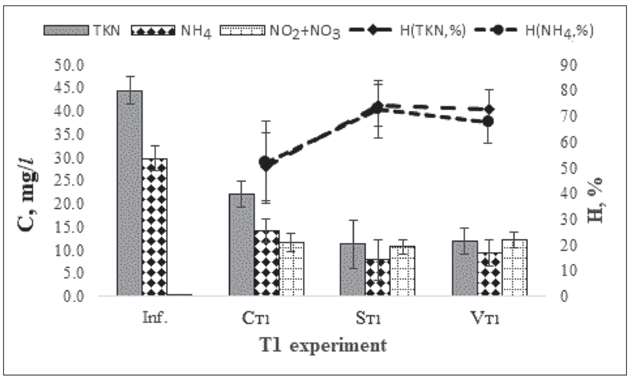

Fig. 6. Nitrogen removal efficiency at 500 m*l*/min/m² hydraulic loading rate.

decrease in concentrations of these two parameters in both reference and ones with plants. However, the treatment efficiencies of TP and PO_4^{3-} in this case were quite low, i.e., 12.93 ± 12.5% and 19.65 ± 12.68% for the reference system, 23.91 ± 3.17 and 26.05 ± 6.25% for the system using the reed grass; and were 25.91 ± 3.67 and 23.69 ± 5.98% for the system with the vetiver grass, respectively (Fig. 7).

The same low removal efficiencies were observed for TKN, NH_4–N and (NO_2–N + NO_3–N) at T2 loading rate (Fig. 8). The reed grass seemed not to work well at this load or the hydraulic loading rate affected the absorption of nutrient of reed grass to some certain extent, leading to lower treatment competence than the control system (without grass). The system with vetiver grass still performed better than the control at 1000 m*l*/min/m^2, but not as well as that at 500 m*l*/min/m^2 (34% versus 69% for NH_4–N parameter). It should be noted that there was not much nitrification process happening within the systems. That was why the NH_4–N and TKN removal efficiencies were rather modest. Previous study indicated a conversion efficiency of 60% for nitrate using VSS CW at the similar loading rate (Prochaska *et al.*, 2007), which was a bit higher than that in this study.

Treatment efficiency of vertical flow model with loading level of 1500 m*l*/min/m^2 (T3)

At this loading rate, the initial concentrations of TP and PO_4^{3-} were quite low of 1.54 ± 0.8 and 0.19 ± 0.07 mg/*l*, respectively (lower than the permit value).

Still after the VSS CW systems, a decrease in PO_4^{3-} concentration was seen in all testing systems (Fig. 9). The TP removals of reed and vetiver grass varied from 20–30%, which was similar to the previous loading rates. In the reference model, the treatment efficiency of TP was 5.5 ± 7.3% and of PO_4^{3-} was 74.8 ± 5.6%. Meanwhile, the treatment efficiency in the CW model using reed grass was 19.5 ± 7.3% for TP and 60.5 ± 24.4% for PO_4^{3-}, similarly, the treatment efficiency in the CW model using vetiver grass for TP and PO_4^{3-} were 28.7 ± 4.8% and 73.6 ± 10.6%, respectively.

Fig. 10 showed that the efficiency of TKN treatment in reed grass model was 62.9 ± 1.8% and 59.4 ± 0.5% for NH_4–N, in vetiver grass model was 61.1 ± 10.6% for TKN and 55.2 ± 12.3% for NH_4–N. Meanwhile, the corresponding values in the reference model were 48.1 ± 2.7% and 41.4 ± 4.5%. Thus, a large variation in the efficiency of TKN and NH_4–N treatment in both reference and experimental models was recorded (Fig. 10). The nitrogen treatment at this loading rate followed similar trend with that at 500 m*l*/min/m^2, only at slightly different magnitude. The TN and NH_4–N removal rates of both systems with floras were about 60%, which was 25% higher than those of the reference one.

Discussions

The treatment of nitrogen and phosphorous in the CW model was reported to relate to the plant uptake in

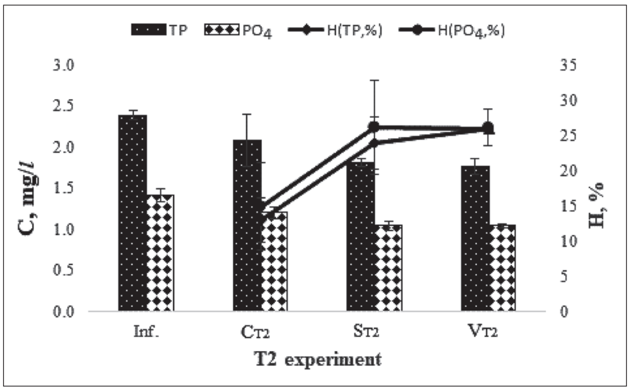

Fig. 7. Phosphous removal efficiency at 1000 m*l*/min/m^2 hydraulic loading rate.

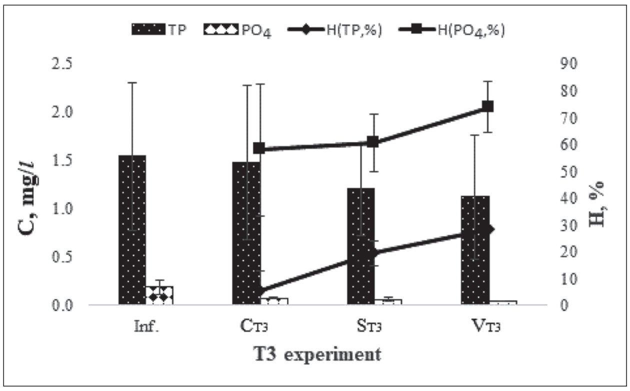

Fig. 9. Phosphous removal efficiency at 1500 m*l*/min/m^2 hydraulic loading rate.

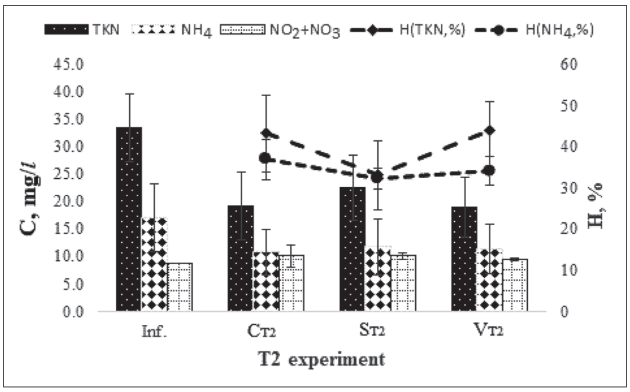

Fig. 8. Nitrogen removal efficiency at 1000 m*l*/min/m^2 hydraulic loading rate.

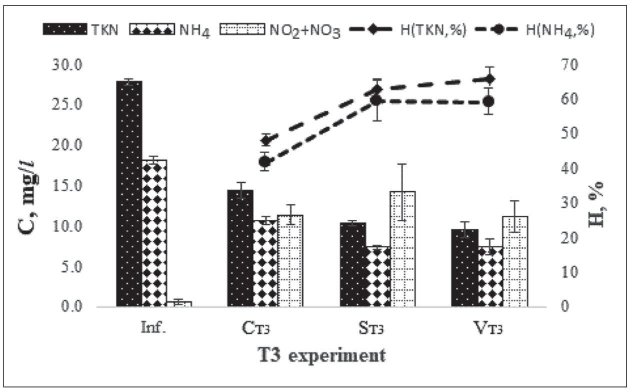

Fig. 10. Nitrogen removal efficiency at 1500 m*l*/min/m^2 hydraulic loading rate.

the system (He and Mankin, 2002; Kadlec and Wallace, 2009). In fact, the presence of plants has increased the biofilms formed around the roots, which play important roles in the oxidation, adsorption or update of the nutrients. The nitrogen transfer was observed better in the constructed wetlands with higher biomass growth rate (Tran *et al*., 2019). According to Vymazal (2010), the CWs were artificial systems designed and used by natural processes under the influence of plants and soil; and they were, in fact, a collection of interactions of microorganisms involved in wastewater treatment. The microorganisms that live in the filter material and stick to the root system of the plant decompose the pollutants for their living activities and the plants also absorb another part. In the study of the role of plants, many researchers found that the number of nitrogen–treated microorganisms in plant–grown treatments was always higher than the reference without plants; thus leading to higher nitrogen treatment efficiency (Lee and Scholz, 2007; Kantawanickul *et al*., 2009). Wang *et al*. (2011) also revealed that the phosphorus decomposition activity of microorganisms in tree–grown experiments was higher than the reference without plants. It should be noted that besides adsorption and plant uptake, the phosphorous could be treated via precipitation (Du *et al*., 2017).

Table 3. ANOVA result of TP removal efficiency (%) for different loading rates (T1, T2 and T3)

Load	Tank	N	Mean	Min	Max
T1	C_{T1}	3	93.4±1.8 ^{d}	92.3	95.5
	S_{T1}	3	95.4±1.5 ^{d}	93.7	96.4
	V_{T1}	3	95.0±0.7 ^{d}	94.6	95.8
T2	C_{T2}	3	12.9±12.5 ^{ab}	1.6	26.4
	S_{T2}	3	23.9±3.2 ^{b}	22.0	27.6
	V_{T2}	3	25.9±3.7 ^{b}	23.5	30.1
T3	C_{T3}	3	5.5±7.4 ^{a}	0.9	14.0
	S_{T3}	3	19.5±7.3 ^{bc}	13.3	27.6
	V_{T3}	3	28.7±4.7 ^{b}	23.5	32.7

Note: $^{a, b, c, d}$*: Means with no common letters differ significantly (p<0.05).*

It was found in the study that the nutrient removal rate of the CWs system with *Canna generalis* tended to decrease gradually when increasing the hydraulic loading rates (Tran *et al*., 2019). Similar trend was obtained in this study, when the loading rates increased, phosphorous removal decreased from about 50% to 25%, but the nitrogen (NH_4–N) did not really follow that trend. It is worth noting that the TP treatment efficiency was better with plants than without plants.

The results of ANOVA showed that the factors of plant types and loading rates both had a significant impact on TP treatment efficiency (Table 3). However, these two factors did not interact with the TP treatment efficiency ($p>0.05$).

For nitrogen removal (TKN and NH_4–N), according to ANOVA statistics, there was a significant impact of plant types on both TKN and NH_4–N treatment efficiency ($p<0.05$). On the other hand, the loading rates also had a substantial influence on the efficiency of TKN treatment (Table 4).

In addition, it was found that there was no statistically significant difference on nitrogen and phosphor treatment efficiency between the reed grass and vetiver grass at the same loading rate ($p>0.05$). The possible explanation may be due to the mature of the plants. In this study, the tests were conducted after the floras were planted for 5 months (from the date of seeding into the CW testing systems). At this age, they might be not mature enough to establish a strong root system and make a difference in absorption capacities by the two species (reed and vetiver). Wang *et al*. (2011) determined that the impact of accelerating nutrient uptake by plants in the fast growing stage was unknown and root microbial community usually was more active at the stage of being mature. Another possible explanation for the difference in phosphorous and nitrogen removal was that more nitrogen–favored microorganisms were available in the biofilms. Nevertheless, the removal of both phosphorous and nitrogen could be enhanced by adding a waste stabilization pond (WSP) after the constructed wetland (Tran *et al*., 2019).

Table 4. ANOVA results of TKN and NH_4–N removal efficiency (%) for different loading rates (T1, T2 and T3)

			TKN			NH_4–N		
Load	Tank	N	Mean	Min	Max	Mean	Min	Max
T1	C_{T1}	3	50.44±3.37^{bc}	46.63	53.04	52.01±9.83^{bc}	43.35	62.70
	S_{T1}	3	74.23±13.12^{d}	62.94	88.63	72.78±15.96^{d}	62.77	91.20
	V_{T1}	3	72.73±8.20^{d}	63.99	80.26	67.68±11.15^{d}	60.61	80.55
T2	C_{T2}	3	43.21±7.61^{ab}	34.42	47.72	36.89±5.20^{a}	32.62	42.69
	S_{T2}	3	33.10±9.35^{a}	24.74	43.21	32.17±4.97^{a}	26.58	36.10
	V_{T2}	3	43.92±8.36^{ab}	37.54	53.39	34.08±2.63^{a}	31.06	35.82
T3	C_{T3}	3	48.10±2.68^{c}	45.14	50.38	41.43±4.46^{ab}	38.36	46.56
	S_{T3}	3	62.92±1.78^{cd}	61.88	64.98	59.37±0.54^{cd}	58.99	60.00
	V_{T3}	3	65.81±2.85^{d}	63.18	68.84	58.95±5.85^{cd}	52.21	62.77

Note: $^{a, b, c, d}$*: Means with no common letters differ significantly (p<0.05).*

CONCLUSIONS

This study has investigated and evaluated the ability to absorb nutrients (N, P) in contaminated surface water sources. The experiment was designed using randomized complete block design method with two factors, i.e., types of floras (reed grass and vetiver) and hydraulic loading rates. (500 m*l*/min/m^2 (T1), 1000 m*l*/min/m^2 (T2) and 1500 m*l*/min/m^2 (T3)). It was found that the treatment efficacy of both phosphorous and nitrogen was the highest at the lowest loading rate of 500 m*l*/min/m^2 (or 0.72 m^3/m^2/d). In particular, the TP, PO_4^{3-}; TKN and NH_4–N removal efficiencies were 95.4 ± 1.5; 54.4 ± 8.5%; 74 ± 17% and 68 ± 21% for reed grass, respectively, while they were 95.0 ± 0.7, 50.1 ± 11.5%, 68 ± 16% and 64 ± 15%, respectively, for vetiver grass. The reference (without flora) was 20–30% lower in all removal rates. As the loading rates increased, the removal rates decreased accordingly and varied with types of plants. Besides the loading rate, and the type of plants, the plant's maturity might impact the formation of microorganism community in the plant roots, leading to the variation in the nutrient removal. In overall, the constructed wetland systems helped treat the wastewater to meet the national technical regulation on surface water quality, used for agricultural irrigation purposes (QCVN 08–MT: 2015/BTNMT, Column B1).

AUTHOR CONTRIBUTIONS

Nguyen Minh KY, Nguyen Tri Quang HUNG and Nguyen Cong MANH were resposible for setting up the experiment models and doing the experiments. Bui Quoc LAP supervised the experiment activities, prepared the manuscript and played the role of the corresponding author. Huyen Thi Thanh DANG supported to data handling and analysis as well as manuscript editing. Akinori OZAKI supported to the manuscript arrangement and revision.

ACKNOWLEDGMENTS

The authors express grateful acknowledgement to the Nong Lam University of Ho Chi Minh for providing funds and test site for this research.

REFERENCES

Abou–Elela S. I., M. S. Hellal 2012. Municipal wastewater treatment using vertical flow constructed wetlands planted with Canna, Phragmites and Cyprus. *Ecological Engineering.*, **47**: 209–213

Aboubacar, S., R. Mohamed, A. Jamal, A. Omar and E. Samira 2018. Exploitation of Phragmites australis (Reeds) in Filter Basins for the Treatment of Wastewater. *Journal of Environmental Science and Technology*, **11**: 56–67

Badejo, A. A., D. O. Omole and Ndambuki 2018. Municipal wastewater management using Vetiveria zizanioides planted in vertical flow constructed wetland. *Applied Water Science*, **8**: 110

Brix, H., A. C. Arias 2005. The use of vertical flow constructed welands for on–site treatment of domestic wastewater: New Danish guidelines. *Ecological Engineering.*, **25**: 491–500

Carpenter, S. R., N. F. Caraco, D.L. Correll, R. W. Howarth, A. N. Sharpley, V. H. Smith 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. *The Ecological Society of America*, **8**(3): 559–568

Dallas, S., B. Scheffe, G. Ho 2004. Reedbeds for greywater treatment–case study in Santa Elena–Monteverde, Costa Rica, Central America. *Ecological Engineering*, **23**: 55–61

Danh, L. T., P. Truong, R. Mammucari, T. Tran, N. Foster 2009. Vetiver grass, Vetiveria zizanioides: a choice plant for phytoremediation of heavy metals and organic waster. *International Journal of Phytoremediation*, **11**: 664–691

Datta, R., P. Das, S. Smith, P. Punamiya, D. M. Ramanthan, R. Reddy, D. Sarkar 2013. Phytoremediation potential of vetiver grass (Vetiveria zizanioides L.) for tetracycline. *International Journal of Phytoremediation*, **15**: 343–351

Du, L., Chen, Q., Liu, P., Zhang, X., Wang, H., Zhou, Q., Xu, D., Wu, Z 2017. Phosphorus Removal Performance and Biological Dephosphorization Process in Treating Reclaimed Water by Integrated Vertical–Flow Constructed Wetlands (IVCWs). *Bioresource Technology*. **243**: 204–211

Dudai, N., E. Putievsky, D. Chaimovitch, M. Ben–Hur 2006. Growth management of vetiver (Vetiveria zizanioides) under Mediterranean conditions. *Journal of Environmental Management*, **81**: 63–71

Effendi, H., P. C. Delis, M. Krisanti, S. Hariyadi 2015. The performance of nile tilapia (Oreochromis niloticus) and vetiver grass (Vetiveria zizanioides) concurrently cultivated in aquaponic system. *Advanced Environmental Biology*, **9**(24): 382–388

ElZein, Z., A. Abdou, G. AbdEl 2016. Constructed Wetlands as a Sustainable Wastewater Treatment Method in Communities. *Procedia Environmental Sciences*, **34**: 605–617

Eriksson, E., K. Auffarth, M. Henze and A. Ledin 2002. Characteristics of grey wastewater. *Urban Water*, **4**(1): 85–104

Farid, M., M. Irshad, M. Fawad, Z. Ali, A. E. Eneji, N. Aurangzeb, A. Mohammad, B. Ali 2014. Effect of cyclic phytoremediation with different wetland plants on municipal wastewater. *International Journal of Phytoremediation*, **16**(6): 572–581

Guy, W., O. G. Mark, S. G. Paul, G. Vladislav, H. Sally, L. Antoine, M. Björn, G. M. Brendan, D.T. Scott, C. Helen, D. Mike, E. Arturo, F. Verónica, A. S. G. Manuel, F. Tadeusz, O. L. Jean, N. Marius, P. Jesús, R. Geta, S. Markus, V. Angheluta, B. M. V. Lena, C. Eric 2012. Continental–Scale Effects of Nutrient Pollution on Stream Ecosystem Functioning. *Science*, **336**(6087): 1438–1440

Havens, KJ, H. Berquist, W. I. Priest 2003. Common reed grass, Phragmites australis, expansion into constructed wetlands: Are we mortgaging our wetland future? *Estuaries*, **26**: 417

He, Q. and K. Mankin 2002. Performance variation of COD and removal of nitrogen removal by vegetated submerged bed wetlands. *Journal American Water Resource Association*, **38**: 1679–1689

Indrayatie, E. R., W. H. Utomo, E. Handayanto, C. W. N. Anderson 2013. The use of vetiver (Vetiveria zizanioides L.) for then remediation of wastewater discharged from tapioca factories. *Journal of Environmental Waste Management*, **12**(1): 1–16

Jarvie, H. P., B. A. Whitton, C. Neal 1998. Nitrogen and phosphorus in east coast British rivers: Speciation, sources and biological significance. *Science of The Total Environment*, **210–211**: 79–109

Kadlec, R. H.; Knight, R. L., (1996). *Treatment wetlands*, 1st Edition. CRC Press, Boca Raton, Florida

Kadlec, R. H. and S. D. Wallace 2009. *Treatment Wetlands*. CRC Press/Lewis Pucblishers, Boca Raton, FL

Kantawanickul, S., S. Kladprasert, H. Brix 2009. Treatment of high–strenght wastewater in tropical vertical flow constructed wetlands planted with Typha angustifolia and Cyperus involucratus. *Ecological Engineering*, **35**: 238–247

Katarzyna, S., H. G. Magdalena 2017. The use of constructed wetlands for the treatment of industrial wastewater. *Journal of Water and Land Development*, **34**: 233–240

Lee, B., M. Scholz 2007 What is the role of Phragmites australis in experimental constructed wetland filters treating urban run–

off? *Ecological Engineering*, **29**: 87–95

Lu, X., M. Kruatrachue, P. Pokethitiyook, K. Homyok 2004. Removal of Cadmium and Zinc by Water Hyacinth., Eichhornia crassipes. *Science Asia*, **30**: 93–103

Maimon, A., A. Tal, E. Friedler and A. Gross 2010. Safe on–site reuse of greywater for irrigation–a critical review of current guidelines. *Environmental Science and Technology*, **44**: 3213–3220

Manuel, J. 2014. Nutrient pollution: a persistent threat to waterways. *Environmental health perspectives*, **122**(11): A304–A309

Mirco, M. and T. Attilio 2013. Evapotranspiration from pilot–scale constructed wetlands planted with Phragmites australis in a Mediterranean environment. *Journal of Environmental Science and Health*, **48**(5): 568–580

Muvea, F. M., Ogendi, G. M., Omondi, S. O. 2019. Nutrient removal efficiency by floating macrophytes; Lemna minor and Azolla pinnata in a constructed wetland. *Global Journal of Environmental Science and Management*, **5**(4): 415–430

Prochaska, C. A., A. I. Zouboulis, K. M. Eskridge 2007. Performance of pilot–scale vertical–flow constructed wetlands, as affected by season, substrate, hydraulic load and frequency of application of simulated urban sewage. *Ecological Engineering*, **31**: 57–66

Roongtanakiat, N. and P. Chairoj 2001. Uptake Potential of Some Heavy Metals by Vetiver Grass. *Kasersart J.* (*Nat. Sci.*)., **35**: 46–50

Seroja, R., H. Effendi, S. Hariyadi 2018. Tofu wastewater treatment using vetiver grass (Vetiveria zizanioides) and zeliac. *Applied Water Science*, **8**: 2

Tran, D. H., Vi, T. M. H., Dang, T. T. H., Narbaitz, R. 2019. Pollutant removal by Canna Generalis in tropical constructed wetlands for domestic wastewater treatment. *Global Journal of Environmental Science and Management*, **5**(3): 331–344

Travis, M. J., A. Wiel–Shafran, N. Weisbrod, E. Adar and A. Gross 2010. Greywater reuse for irrigation: effect on soil properties. *Science of The Total Environment*, **408**: 2501–2508

Truong, P. N., Y. K. Foong, M. Guthrie, Y. T. Hung 2010. Phytoremediation of heavy metal contaminated soils and water using vetiver grass. *Environ. Bioengineering*, **11**: 233–275

Vymazal, J. 2002. The use of subsurface constructed wetlands for wastewater in Czech Republic: 10 years experience. *Ecological Engineering*, **18**: 633–646

Vymazal, J. 2009. The use of constructed wetlands with horizontal sub–surface flow for various types of wastewater. *Ecological Engineering*, **35**: 1–17

Vymazal, J. 2010. Constructed Wetlands for Wastewater Treatment. *Water*, **2**: 530–549

Wang, R., Baldy V., Perissol C., N. Korboulewsky 2012. Influence of plants on microbial activity in a vertical dowflow wetland system treating waste activated sludge with high organic matter concentrations. *Journal of Environmental Management*, **95**: S158–S164

Xinyu, L., C. Hontao, J. Xueyan, Y. Zhigang, Y. Qingzhen 2017. Impacts of human activities on nutrient transport in the Yellow River: The role of the Water–Sediment Regulation Scheme. *Science of The Total Environment*, **592**: 161–170

Zeshan, A., M. Ashiq, R. Yousaf, M. Q. Umar, NM. Riffat 2018. Treatment efficiency of a hybrid constructed wetland system for municipal wastewater and its suitability for crop irrigation. *International Journal of Phytoremediation*, **20**(11): 1152–1161

Zhang, D. Q., Jinadasa, K., Gersberg, R. M., Liu, Y., Ng, W. J., Tan, S. K. 2014. Application of constructed wetlands for wastewater treatment in developing countries: A review of recent developments (2000–2013). *Journal of Environment Management*. **141**: 116–131

Zurita, F. D. A. 2009. Treatment of domestic wastwater and production of commercial flower. *Ecological Engineering*, **35**(5): 861–869