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

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

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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/m², 1000 ml/min/m² and 1500 ml/min/m² were tried. The results showed that the nutrient removal percentage was highest at the hydraulic loading rate of 500 ml/min/m². 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 *Thalassidroma alata*; 52.8% and 40% for *Anthurium andreaeanum*, respectively; while they were 15% and 52% for *Canna indica*; 23.97% and 30.69% for *Lemna minor*; 25.57% and

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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 Chairaj, 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 km² 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/m² (T1), 1000 ml/min/m² (T2) and 1500 ml/min/m² (T3), are shown in Table 1. It can be seen from Table 1 that amonium nitrogen (NH₄-N) was higher than the standard value most of the time, while phosphate (PO₄³⁻) 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 *Vetiveria 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/m² (T1), 1000 ml/min/m² (T2) and 1500 ml/min/m² (T3)

*Phragmites australis**Vetiveria zizanioides***Fig. 2.** Flora used in the experiment.

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/m² (T1), 1000 ml/min/m² (T2) and 1500 ml/min/m² (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

Fig. 3. Diagram of experiment set up. **Fig. 4.** Cross – section of Vertical subsurface flow constructed wetland system.**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}

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 ($\phi = 1 \div 2$ 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 ($\phi = 21$ mm) from the top, then it was filtered through medial vertically and collected at the bottom by a water pipe ($\phi = 60$ 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, $\text{NH}_4\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$. 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:

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

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

Fig. 5. Phosphorus removal efficiency at 500 ml/min/m² hydraulic loading rate.

the reference CW model were 93.4 ± 1.8 and $61.6 \pm 29.2\%$, in the CW model using reed grass were 95.4 ± 1.5 and $54.4 \pm 8.5\%$; and in the CW model using vetiver grass were 95.0 ± 0.7 and $50.1 \pm 11.5\%$, 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, $\text{NH}_4\text{-N}$) (Fig. 6). Contrary to the decline of TKN and $\text{NH}_4\text{-N}$ concentrations, the concentrations of ($\text{NO}_2\text{-N} + \text{NO}_3\text{-N}$) increased more than 100 times in both the control and the ones with floras. This proved that nitrogen has well transferred from $\text{NH}_4\text{-N}$ 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 $\text{NH}_4\text{-N}$ concentration was lower than the standard eventually. The efficiency of TKN treatment by reed grass was $74 \pm 17\%$ and $68 \pm 21\%$ for $\text{NH}_4\text{-N}$; the similar was observed for vetiver grass of $68 \pm 16\%$ and $64 \pm 15\%$, respectively. Meanwhile, the corresponding values in the reference CW model were $60 \pm 13\%$ and $52 \pm 10\%$. 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 $\text{NH}_4\text{-N}$ 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 ml/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. 6. Nitrogen removal efficiency at 500 ml/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., $12.93 \pm 12.5\%$ and $19.65 \pm 12.68\%$ for the reference system, 23.91 ± 3.17 and $26.05 \pm 6.25\%$ for the system using the reed grass; and were 25.91 ± 3.67 and $23.69 \pm 5.98\%$ for the system with the vetiver grass, respectively (Fig. 7).

The same low removal efficiencies were observed for TKN, $\text{NH}_4\text{-N}$ and ($\text{NO}_2\text{-N} + \text{NO}_3\text{-N}$) 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 ml/min/m^2 , but not as well as that at 500 ml/min/m^2 (34% versus 69% for $\text{NH}_4\text{-N}$ parameter). It should be noted that there was not much nitrification process happening within the systems. That was why the $\text{NH}_4\text{-N}$ 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 ml/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 $5.5 \pm 7.3\%$ and of PO_4^{3-} was $74.8 \pm 5.6\%$. Meanwhile, the treatment efficiency in the CW model using reed grass was $19.5 \pm 7.3\%$ for TP and $60.5 \pm 24.4\%$ for PO_4^{3-} , similarly, the treatment efficiency in the CW model using vetiver grass for TP and PO_4^{3-} were $28.7 \pm 4.8\%$ and $73.6 \pm 10.6\%$, respectively.

Fig. 10 showed that the efficiency of TKN treatment in reed grass model was $62.9 \pm 1.8\%$ and $59.4 \pm 0.5\%$ for $\text{NH}_4\text{-N}$, in vetiver grass model was $61.1 \pm 10.6\%$ for TKN and $55.2 \pm 12.3\%$ for $\text{NH}_4\text{-N}$. Meanwhile, the corresponding values in the reference model were $48.1 \pm 2.7\%$ and $41.4 \pm 4.5\%$. Thus, a large variation in the efficiency of TKN and $\text{NH}_4\text{-N}$ 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 ml/min/m^2 , only at slightly different magnitude. The TN and $\text{NH}_4\text{-N}$ 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. Phosphorus removal efficiency at 1000 ml/min/m^2 hydraulic loading rate.

Fig. 9. Phosphorus removal efficiency at 1500 ml/min/m^2 hydraulic loading rate.

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

Fig. 10. Nitrogen removal efficiency at 1500 ml/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 uptake 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 (NH₄-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 NH₄-N), according to ANOVA statistics, there was a significant impact of plant types on both TKN and NH₄-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 phosphorus 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 NH₄-N removal efficiency (%) for different loading rates (T1, T2 and T3)

Load	Tank	N	TKN			NH ₄ -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 ml/min/m² (T1), 1000 ml/min/m² (T2) and 1500 ml/min/m² (T3)). It was found that the treatment efficacy of both phosphorous and nitrogen was the highest at the lowest loading rate of 500 ml/min/m² (or 0.72 m³/m²/d). In particular, the TP, PO₄³⁻; TKN and NH₄-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 responsible 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.

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