Green Infrastructure for Buildings in the Tropical Coupling with Domestic Wastewater Treatment

Vo Thi Dieu Hien and Bui Xuan Thanh

Abstract— *This paper presented the results of study evaluating nutrients removal from domestic wastewater by four plants grown on horizontal subsurface flow wetland flat roof system (WRs). This study's plants includedCyperusjavanicusHoutt (WR1), Eleusineindica(L.)Gaertn (WR2),Struchiumsparganophorum (L.) Kuntze (WR3) and KyllingabrevifoliaRottb (WR4). Four plants grew normally after 60 days under acclimatization hydraulic loading rates (HLR0) 296 ± 10 m^3/ha.daywith domestic wastewater as a nutrient source. The 4 WRs were operated at 2 HLR of 247 - 320 m^3/ha.day (HLR1), 353 - 403 m^3/ha.day (HLR2) with organic load rate of 32 ± 12, 56 ± 26 kgCOD/ha.day respectively. Overall, nutrient removal of WR1 and WR4 were likely higher than WR2 and WR3 under operating conditions of WRs. The average phosphorus removal efficiencies of WR1 and WR4 were approximately 68 - 78 % and 72 - 81 %, respectively and the average nitrogen removal efficiencies of WR1 and WR4 were approximately 72 - 73 % and 58 - 67 %, respectively. The phosphorus removal rates of WR1 and WR4 were 0.7 ± 0.3 and 0.8 ± 0.3 kgTP/ha.day respectively in HLR1 and the nitrogen removal rates of WR1 and WR4 were 12 ± 2 and 12 ± 3kgTN/ha.day in HLR2.*

Keywords— **Cyperusjavanicus Houtt, Eleusineindica (L.) Gaertn, green roof, Kyllingabrevifolia Rottb, Struchiumsparganophorum (L.) Kuntze, wetland roof.**

1. INTRODUCTION

Domestic water is becoming more scarce and polluted. Most domestic wastewater in urban neighborhoods, suburban and rural areas is not being treated properly. Wastewater from the toilet only undergoes pretreatment in septic tanks. Hence, this has been producing an unsatisfactory discharge quality.

Constructed wetland (CW) is one of the treatments that is highly effective, simple in construction and operation, low energy cost and is widely used around the world. In Europe, CV on horizontal subsurface flow has been used to treat level 2 domestic sewage and urban. CV on surface flow is capable of removing high levels of heavy metals and organic substances in wastewater industry [1]. In addition, the use of wetland buffer zone is also very effective in controlling phosphorus runoff from agricultural areas. However, limitation of this method is very expensive per area."Green roof" (GR), the roof is utilized to increase tree planting "green area". Not only aesthetic sense and offers environmentally friendly, green roofs also have the ability to process waste water and save energy and increase biodiversity. The combination of CW and GR is created for the purpose of on-site sewage treatment, improving the energy efficiency of buildings, noise reduction for households or population groups, treatment of toxins in the air and increased green space in the city with the appropriate technology, just a simple, space saving, cost of construction and operation of low, medium increases the aesthetic value as a way forward reasonable and feasible decisions.

This paper presented the results of study evaluating nutrients removal from domestic wastewater by four plants grown on horizontal subsurface flow wetland flat roof system (WRs) at hydraulic loading rate (HLR) of 300 m^3/ha d, 400m^3/ha.d and 500 m^3/ha.d. This study's plants include *CyperusjavanicusHoutt* (WR1), *Eleusineindica (L.) Gaertn* (WR2), *Struchiumsparganophorum (L.) Kuntze* (WR3) and *KyllingabrevifoliaRottb* (WR4).

2. MATERIALS AND METHODS

2.1 Experimental setup

The experiments were performed in 4 models with texture, size and similar plant material. The size of each model (length x width x height) is 1800 mm x 600 mm x 150 mm (Fig. 1). Each model is divided into three successive stop working to prevent short-circuit currents. Each compartment dimension (length x width x height) is 1800mm x 200mm x 150mm. At the beginning and end of each model installed water distribution pipes and output tubes (with drill holes) with a diameter of 21 mm to sample for analysis. The layers of materials are place in order from top to bottom. They are surface soil (5mm), sand (95mm) and small rocks (20mm). In the first two models, gravel (100mm thick) is spread throughout the depth. Design water level is 100 mm from the bottom up. Input wastewater is controlled by a needle valve. Place model 600 mm above the ground. For flat roofs, design patterns slope above the ground is 1 %.

Vo Thi Dieu Hien is with Environmental Engineering and Management Research Group, Ton Duc Thang University; Faculty of Environment and Labour Safety, Ton Duc Thang University; No. 19 Nguyen Huu Tho Street, Tan Phong Ward, District 7, Ho Chi Minh City, Vietnam. Email: vothidieuhien@tdt.edu.vn.

Bui Xuan Thanh (corresponding author) is with Faculty of Environment and Natural Resources, Ho Chi Minh City University of Technology (HCMUT), Vietnam. B9, 268 Ly Thuong Kiet str., District 10, Ho Chi Minh City, Viet Nam. Email: thanhait@yahoo.com.

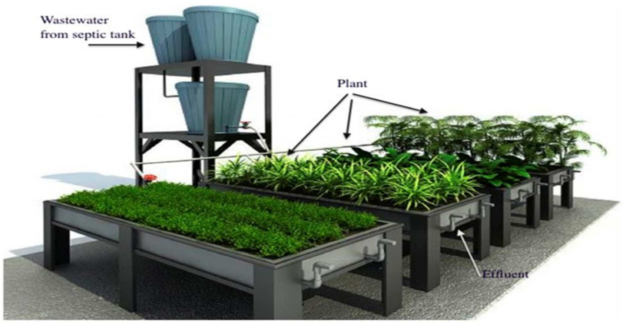

Fig. 1. Model of the WR systems.

2.2. Domestic wastewater

Domestic wastewater was taken from the last chamber of a septic tank in a cafeteria in Ho Chi Minh City University of Technology (HCMUT). The characteristics of wastewater was 114 ± 31 mg COD/L, 46 ± 16 mg TN/L, 0.4 ± 0.1 mg NO_3^--N/L, and 0.9 ± 0.7 mg TP/L. During the study period, wastewater pH varied between 6.3 and 7.7.

2.3. Experimental plants

The selection of plants to study adopted the following criteria: easy to grow, with vigor and ability to thrive in harsh conditions; ability to treat wastewater; aesthetics, broad coverage; locally available and low cost. The plants are described in detail in Table 1.

2.4. Sampling and analysis

2.4.1. Sampling

The influent samples were taken in sewage pipes flowing into 4 models, the effluent samples were taken at the output pipe position at the end of each model. Sample analysis was performed an average of 3 times/week for about 8 to 9 hours. The temperature patterns around the area ranging from 27^{0}C to 30^{0}C.Water samples were collected in plastic bottles. The necessary parameters (COD, TP, NH_4^+-N, NO_2^--N, NO_3^{--}-N, TKN, and SS) were analyzed according to standard methods [2].

Table. 1. Experimental plants on WRs

Plants	**WR1**	**WR2**	**WR3**	**WR4**
Scientific name	*CyperusjavanicusHoutt*	*Eleusineindica (L.) Gaertn*	*Struchiumsparganophorum (L.) Kuntze*	*KyllingabrevifoliaRottb*
Density	12 plants/m^2			
Characteristic	The initial height/ length was shorter than 20 mm.			
Images				

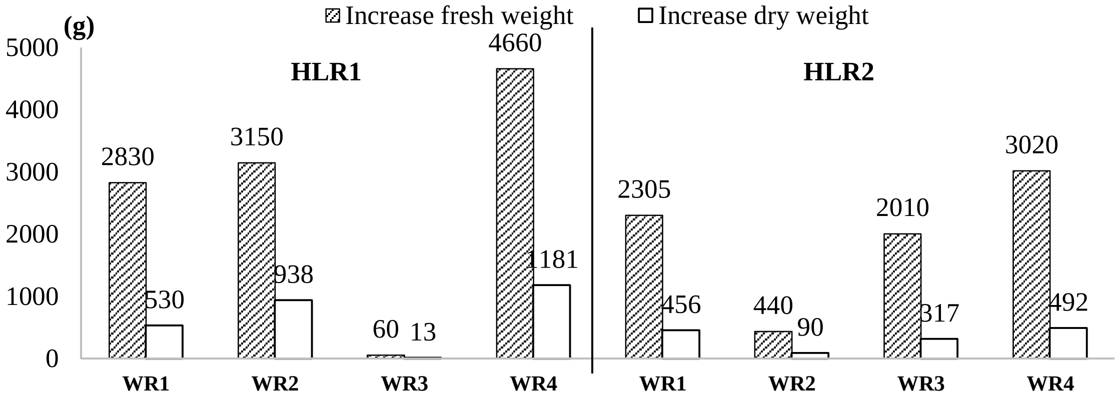

Fig. 2. Increase in dry and fresh weight of plants when finish HLR1 (33 days) and HLR2 (41 days).

3. RESULTS AND DISCUSSION

3.1. Plant growth and acclimatization

Plants of WR1 – WR4 were planted on 12/11/2013 with WR1 – *CyperusjavanicusHoutt*, WR2 – *Eleusineindica (L.) Gaertn*., WR3 – *Struchiumsparganophorum (L.) Kuntze*and WR4 – *KyllingabrevifoliaRottb*. In order for the plants to adapt gradually to the WR conditions, the models were operated with tap water for the first 10 days. At this time, the plants grew slowly and some leaves turned yellow. From day 11, the systems were operated with wastewater to provide nutrients for plants and biofilm development. At this time, leaves of plants turned normal green and grew some new buds. During this period, the hydraulic load rate was about 296 ± 10 m^3/ha.day corresponding to hydraulic retention time (HRT) of about 31 ± 1 hours.

The plants were harvested when a hydraulic loading rate was completed. At the end of HLR1, the fresh weight of plants in WR1, WR2, WR3 and WR4 increased 2,830; 3,150; 60 and 4,660 g respectively, the dry weight were 530; 938; 13 and 1,181 g, respectively. It meant that the growth rate of plants was sorted in descending order to WR4, WR2, WR1 and WR3. At the end of HLR2, the fresh weight of plants in WR1, WR2, WR3 and WR4 increased 2,305; 440; 2,010 and 3,020 g respectively, the dry weight were 456; 90; 317 and 492 g respectively (Fig.2). In other words, the growth rate of the plants changed in which it was sorted in descending order to WR4, WR1, WR3 and WR2.

3.2. Treatment performance

3.2.1. COD removal

COD are removed in CW due to the biodegradation and filtration through media layers. Both aerobic and anaerobic processes reduce organic carbon in CW. Root system creates an ideal environment for the development of suspended adhesive microorganism. Biodegradation occurs when dissolved organic matter is brought in contact with the adhesive microorganism layer on submerged body of plant, root systems and filter material layer. In this study, output COD concentrations were lower than 100 mg/L and complied CITAI standard (2003) of the European for reuse in additional surface water sources, urban landscaping and irrigation in agricultural and quality standards for recycled water to irrigate and clean street in Taiwan (TWEA) [3].

In the acclimatization period of average 288 - 300 m^3/ha.day, COD removal of WR1 was (79 ± 8% or 28 ± 5 kgCOD/ha.day), WR2 was (75 ± 11% or 27 ± 8 kgCOD/ ha.day), WR3 was (82 ± 11% or 30 ± 5 kgCOD/ ha.day) and WR4 was (86 ± 8% or 30 ± 5 kgCOD/ ha.day). For removal efficiency and removal rate, plants of WR3 and WR4 were higher than other plants.

The influent COD concentrations at the average HLR1 (247 - 320 m^3/ha.day) varied from 78 - 168 mg/L. The average effluent COD concentrations ranged from 3 - 49 mg/L which is lower than the wastewater reuse standard of GAZA (2002) for agriculture irrigation purpose (150 mg/L) and TWEA standard for watering plants, washing lines (100 mg/L) [5]. For removal efficiency and removal rate, plants of WR1 and WR4 were higher than other plants. The WR1 – WR4 were (78 ± 7% or 22 ± 9 kgCOD/ ha.day), (73 ± 19% or 21 ± 7 kgCOD/ ha.day), (70 ± 16% or 21 ± 9 kgCOD/ ha.day) and (81 ± 11% or 24 ± 9 kgCOD/ ha.day) (Fig. 3) respectively. At HLR2 (353 - 403 m^3/ha.day), the COD removal efficiencies were about 39 - 88%. The highest efficiency was in WR4 (79 ± 11%). The COD removal efficiencies and rates of WR1 and WR4 were higher than others. In general, the COD removal efficiency of the HLR2 was slightly lower than those of the HLR1. However, the COD removal rate of the HLR2 was higher than those of the HLR1.

The comparison with the experimental results of the before studies, the COD removal rate at HLR2 of this study was higher than the results of the before studies [5] and the removal efficiency was higher than the one of [6, 7, 8].

3.2.2. Nitrogen removal

For constructed wetland environment, the deeper layers of material, the lower the dissolved oxygen gradually creates conditions for denitrification to nitrogen gas occurs.

Input and output Nitrate concentrations were less than 3 mg/L and met the standard of QCVN 14:2008 column B (≤ 50 mg/L) [8], reached the reusing requirements for the purpose of groundwater addition, soil and two lanes improvement in the inner city (Jordan, 2003) (≤ 45 mg/L) [3] and GAZA (2002) for agriculture irrigation purpose (50 mg/L). Almost of effluent NH_4^+-N concentrations were lower than 10 mg/L and reached column B of QCVN 14:2008, soil and two lanes improvement in the inner city (≤ 10 mg/L). All of effluent TN concentrations met the reusing standard of Jordan (2003) for the purpose of groundwater addition (≤ 30 mg/L), soil and two lanes improvement in the inner city (≤ 45 mg/L).

At the HLR1, the average nitrogen removal efficiency (rate) in WR1, WR2, WR3 and WR4 were 72 ± 22% (7.2 ± 3.8 kgTN/ha.day), 48 ± 20% (4.8 ± 2.5 kgTN/ha.day), 59 ± 26% (6.9 ± 5.5 kgTN/ha.day), 58 ± 20% (7.2 ± 4.6 kgTN/ha.day) respectively. This indicates plants of WR1 and WR4 had the best nitrogen removal capacity. The best was the WR4.

At the HLR2, the average nitrogen removal efficiency (rate) in WR1, WR2, WR3 and WR4 were 73 ± 8% (12 ± 2 kgTN/ha.day), 59 ± 15% (10 ± 4 kgTN/ha.day), 68 ± 10% (12 ± 3 kgTN/ha.day), 67 ± 13% (12 ± 3 kgTN/ha.day) respectively. In comparison to HLR1, the removal rates of plants were stable and increased remarkably. The best was the plant WR1 (Fig. 4).In general, the TN removal rate and efficiency of this study was lower than the results of the before studies [5] but it was higher than the one of [9].

3.2.3. Phosphorous removal

At the HLR1, the average TP removal efficiency (rate) in WR1, WR2, WR3 and WR4 were 94 ± 6% (0.7 ± 0.3 kgTP/ha.day), 54 ± 17% (0.5 ± 0.4 kgTP/ha.day), 53 ± 16% (0.5 ± 0.3 kgTP/ha.day), 91 ± 8% (0.8 ± 0.3 kgTP/ha.day) respectively. This indicates the plant of WR4 had the best TP removal capacity. The difference of TP removal in these plants of WR1, WR2 and WR3 was insignificant.

At the HLR2, the average nitrogen removal efficiency (rate) in WR1, WR2, WR3 and WR4 were 74 ± 16% (0.4 ± 0.2 kgTP/ha.day), 62 ± 23% (0.4 ± 0.2 kgTP/ha.day), 83 ± 8% (0.5 ± 0.3 kgTP/ha.day), 79 ± 12% (0.5 ± 0.2 kgTP/ha.day) respectively. This indicates the difference of TP removal in the plants was insignificant. In comparison to the HLR1, the removal rates of the plants tended to decrease (Fig. 5).

For the removal efficiency, this study was higher than [5] and [9]. However, for the removal rate, this study was lower than [5].

The effluent TP concentration of all WRs was less than 6 mg/L which complied with Vietnamese national technical regulation on domestic wastewater (QCVN 14:2008/BTNMT, level A). According to CITAI (2003), water reuse for irrigation purposes have TP ≤ 2 mg/L. The recycled water standard for landscaping purposes is recommended for HCM city with ≤ 6 mg/L (Dan et al., 2008). The reuse water standard of GAZA (2002) for seawater outfall is ≤ 5 mg/L (PO4 – P). Therefore, WRs effluent TP concentrations can be used for reuse purposes.

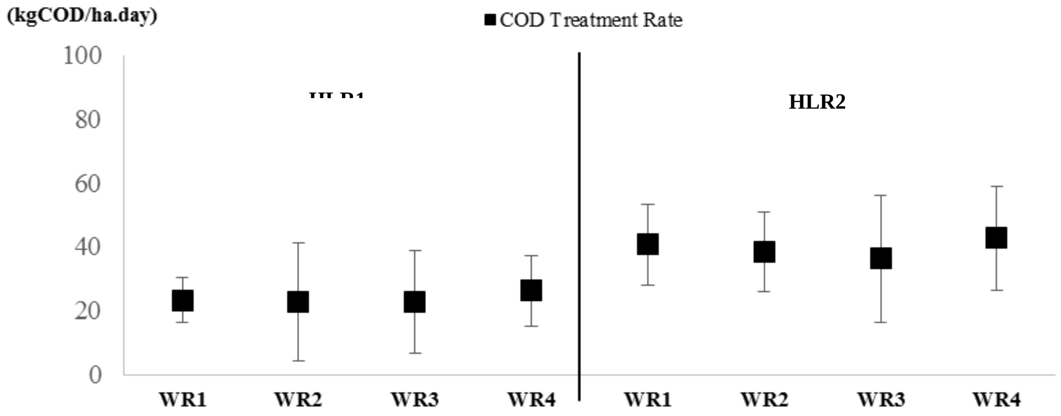

Fig. 3. COD removal rate in HLR1 and HLR2.

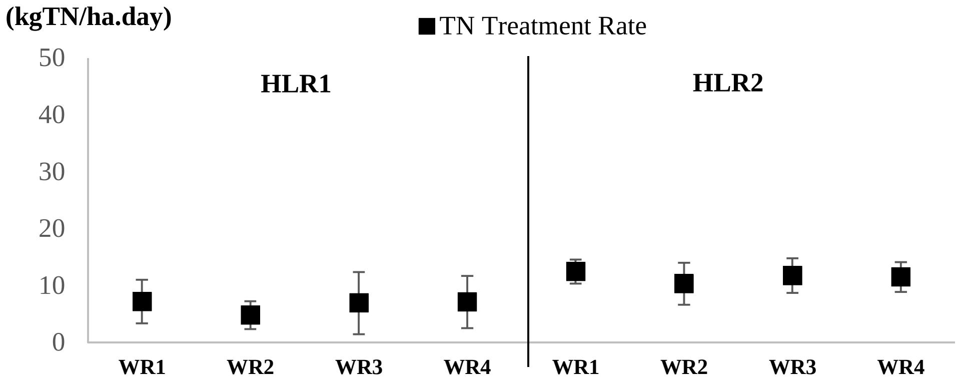

Fig. 4. Total nitrogen removal rate in HLR1 and HLR2.

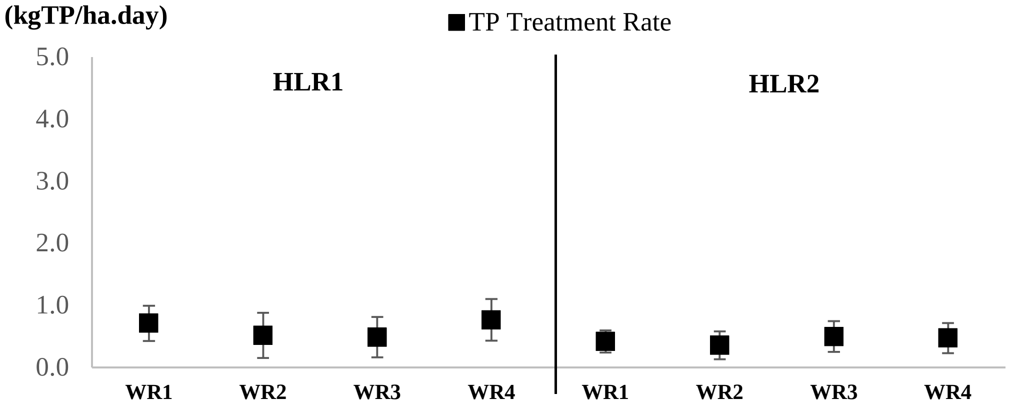

Fig. 5. TP removal rate in HLR1 and HLR2

4. CONCLUSION

The removal efficiencies of *CyperusjavanicusHoutt* (WR1) and *KyllingabrevifoliaRottb* (WR4) were higher than others. WR4 is the best out of the four experimental plants. The nutrient removal efficiencies as well as the nutrient removal rates of the plant in WR4 were 7.2 ± 4.6 kgTN/ha.day and 0.8 ± 0.3 kgTP/ha.day at HLR1, and was 12 ± 3 kgTN/ha.day and 0.5 ± 0.2 kgTP/ha.day at HLR2. Hence, making WR4 was the highest plant among the experimental plants in terms of nutrient removal efficiencies and nutrient removal rates.

REFERENCES

[1] Solano, M.L., Soriano, P., and Ciria, M.P. (2004). Constructed wetlands as a sustainable solution for wastewater treatment in small villages. Biosystems Engineering. 87: 109-118.

[2] APHA, Standard Methods for Examination of Water and Wastewater (1998). 20th version, American Public Health Association, Washington, DC.

[3] Dan N.P et al. Research reuse of treated domestic wastewater for Ho Chi Minh City - Research Report (2008). Department of Science and Technology of Ho Chi Minh City.

[4] Annika K. and Julika P. Lesson D1 - Guidelines and Standards for Wastewater Reuse (2013). Adelphi Research Berlin - The EMWater project.http://cgi.tu-harburg.de/~awwweb/wbt/emwater/documents/lesson_d1.pdf.

[5] Thanh B. X., Van P.T.H., TinN.T., Hien V.T.D., Dan N.P., Koottatep T., Performance of wetland roof with *Melampodiumpaludosum* treating septic tank effluent (2013).*Desalination Water Treatment*, 52, 1070-1076.

[6] Saeed T., Sun G., A review on nitrogen and organics removal mechanisms in subsurface flow constructed wetlands: Dependency on environmental parameters, operating conditions and supporting media (2012).*Journal of Environmental Management*, 112, 429–448.

[7] Yang Q, Chen ZH, Zhao JG, Gu BH (2007).Contaminant removal of domestic wastewater by constructed wetlands: Effects of plant species, *Journal of Intergrative Plant Biology*, 49(4), 437−446.

[8] VN MONRE- Viet Nam Ministry of Natural Resources and Environment (2008). National technical regulation on domestic wastewater treatment. QCVN 14:2008/BTNMT.

[9] Van, P.T.H., Tin, N.T., Hien, V.T.D., Quan, T.M., Thanh, B.X., Hang, V.T., Tuc, D.Q., Dan, N.P., Khoa, L.V., Phu, V.L., Son, N.T., Luong, N.D., Kwon, E., Park, C., Jung, J., Yoon, I. & Lee, S. (2014). Nutrient removal by different plants in wetland roof systems treating domestic wastewater, *Desalination and Water Treatment*, 1-9; ISSN: 1944-3994).