



# Performance of Wetland Roof Treating Domestic Wastewater in the Tropic Urban Area

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## ABSTRACT

This study evaluated the treatment efficiency of four plants, namely *Axonopus compressus* (2); *Melampodium paludosum* (3); *Tradescantia spathacea compacta* (4); *Catharanthus roseus* (L) G. Don (5), in the wetland roof system (WR). Five WRs (including the control system) were operated at the two hydraulic loading rates (HLR1 of 220 m<sup>3</sup>/ha.day and HLR2 of 417 m<sup>3</sup>/ha.day), corresponding to organic loading rates (OLR1 of 31 kg COD/ha.day and OLR2 of 71 kg COD/ha.day). The studied plants had the ability to grow in the roof conditions with domestic wastewater as a nutrient source. The removal efficiencies (mean ± SD) of the control (1), (2), (3), (4), (5) were approximately 55 ± 4; 68 ± 5; 71 ± 4; 65 ± 5 and 65 ± 10% (or 20 ± 2; 25 ± 5; 30 ± 7; 25 ± 3 and 23 ± 3 kg COD/ha.day) and 16 ± 6; 41 ± 9; 40 ± 20; 44 ± 22; 7 ± 6% (1.8 ± 0.8; 4.8 ± 0.8; 4.4 ± 2.2; 4.8 ± 2.2; 0.6 ± 0.5 g TP/ha.day) and 41 ± 5; 56 ± 3; 59 ± 4; 55 ± 7; 54 ± 9% (or 1.7 ± 0.3; 2.4 ± 0.2; 2.5 ± 0.3; 2.4 ± 0.4; 2.2 ± 0.5 kg TN/ha.day) at 192 - 247 m<sup>3</sup>/ha.day of HLR, respectively for COD, TP and TN. Generally, *Axonopus compressus* (2) and *Melampodium paludosum* (3) were the most suitable plants treating domestic wastewater for the conditions of WR.

**Keywords:** Wetland roof; *Axonopus compressus*; *Melampodium paludosum*; Hydraulic loading rate

## 1. INTRODUCTION

Currently, most domestic wastewater in the urban residential, suburban and rural areas in Viet Nam is not treated thoroughly and effectively. Wastewater from the toilets has been treated preliminarily in septic tanks, or osmosis partitions and effluent water quality does not satisfy discharge requirements of National Technical Regulation for Domestic Wastewater (QCVN 14:2008/BTNMT). This contributes to the groundwater and surface water pollution which will affect public

health. In the current conditions of Viet Nam, the studies of wastewater purification for households are necessary solution. Besides, this technology has to be easy-to-operate, low-cost and environmental friendly.

This model of wetland roof system has structure and operating principle like conventional constructed wetland (CW). The WR can be set on handrail, terrace or any flat roof of a building. The WR has light structure, shallow materials types and short plant height to be located in the certain places. Besides the capacity of wastewater treatment (Blumberg), WR also helps to decrease flood risk in cities (Bengtsson et al., 2005; Mentens et al., 2006). It increases

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energy saving (Fang, 2008; Wong et al., 2008), biodiversity (Gedge et al., 2005; Dunnett et al., 2008) and urban green raft (Berndtsson et al., 2009). It reduces the emission of the greenhouse gas (Li et al., 2010).

This study aims to develop a wetland roof system which could treat domestic wastewater and improve the green area for an urbanized area. The study content includes the survey the adaptability of the four plants to select the suitable plants for wetland roof system and evaluation of treatment efficiency of the systems at OLR of 31-71 kg COD/ha.day (or HLR of 192-445 m<sup>3</sup>/ha.day).

## 2. MATERIAL AND METHODS

### 2.1 Experimental Setup

Experiments were conducted in a transparent acrylic box including five separated channels which were for control WR (1) and for four WRs with plants (2), (3), (4) and (5) (See Table 2). The dimension of the system is 1.5 m in length x 0.75 m in wide x 0.3 m in height. The layers of materials are placed in order from top to bottom (10 mm of surface

sand; 20 mm of natural soil 20 mm; 120 mm of sand and 50 mm of small rocks). The water level is 100 mm. At the two ends of each channel, gravel is packed in block to avoid clogging (100 mm in length). The porosity of the materials is 0.25. The slope of channel is one percent. Wastewater flowed from the leveled container gravitational into the WRs. The perforated distribution pipes has diameter of 21 mm. These WRs were operated similar to the principles of a conventional horizontal subsurface flow constructed wetland. The different points were the plants and the height of filter media. The system was located in the campus of Ho Chi Minh City University of Technology, Viet Nam where the conditions were similar to those of a flat roof.

Plants were grown on 17/2/2011 (day 1). Tap-water was used to water the plants for the first 7 days. Wastewater was introduced to the system from the day 8 onwards. No samples were collected from the model from day 8 to day 46.





Five WRs (including the control system) were operated at the two average hydraulic loading rates, HLR1 of 220 and HLR2 of 417 m<sup>3</sup>/ha.day, which were equal to organic loading rate of 31 and 71 kg COD/ha.day.

**Table 1** Experimental conditions

Period	System	HLR (m <sup>3</sup> /ha.day)	OLR (kgCOD/ha. day)	Flow (L/day)	Influent COD (mg/L)	HRT (h)
<b>1</b> (day 8-81)	(1)	218 ± 10	37 ± 3	4.9 ± 0.2	174 ± 11	29 ± 4
	(2)	222 ± 13	38 ± 4	5.0 ± 0.3		30 ± 9
	(3)	225 ± 13	39 ± 3	5.1 ± 0.3		26 ± 4
	(4)	227 ± 4	39 ± 3	5.1 ± 0.1		27 ± 1
	(5)	209 ± 10	36 ± 3	4.7 ± 0.2		29 ± 2
<b>2</b> (day 82-109)	(1)	381 ± 31	60 ± 5	8.6 ± 0.7	157 ± 9	16 ± 1
	(2)	430 ± 15	67 ± 2	9.6 ± 0.4		14 ± 1
	(3)	429 ± 5	67 ± 4	9.6 ± 0.1		14 ± 0
	(4)	419 ± 5	66 ± 4	9.4 ± 0.1		14 ± 1
	(5)	426 ± 0	67 ± 4	9.6 ± 0.1		14 ± 0

**Note:** Day 76 started a rain. For HLR1, there was no significant different among the sections. For HLR2, (1) was obvious lower than others. For OLR of the sections, there wasn't the significant different.

**Table 2** Experimental plants on wetland roof

Plants	(2)	(3)	(4)	(5)
Scientific name	<i>Axonopus compress-us</i>	<i>Melampo-dium paludosum</i>	<i>Tradescantia spathacea Compacta</i>	<i>Catharanthus roseus (L.) G. Don</i>
Density	213 buds/m <sup>2</sup>		44 trees/ m <sup>2</sup>	35 trees/ m <sup>2</sup>
Image				

## 2.2 Wastewater

Domestic wastewater was taken from the last chamber of a typical septic tank. The characteristics of wastewater during the operation period was  $168 \pm 13$  mg COD/L,  $12.3 \pm 9.1$  mg TN/L,  $0.33 \pm 0.11$  mg NO<sub>3</sub>-N/L and  $0.06 \pm 0.02$  mg TP/L. Wastewater pH values varied between 7 – 8.

## 2.3 Experimental plants

The criteria for selection of plants include easy to plant; vitality and strong development in harsh conditions; ability to treat wastewater; ability to develop widespread and cover the surface; plant with cluster root. The plants which are available in local and low in cost are preferential. In addition, the height of plants should be less than 0.5 m to avoid the effect of wind. The used plants are described in Table 2.

## 2.4 Analytical Methods

The WRs were observed throughout the experimental period for the number, the height and the expansion of plants. At the start and the end of experiment, plant was dried at 70<sup>0</sup>C until constant weights achieved to measure the dry weight. The influent (at distributor) and effluent samples were collected twice a week to determine

parameters of pH, COD, TP, TN, ammonia, nitrite, and nitrate. The analytical methods were according to standard methods (APHA, 1998). Comparisons of concentrations in effluent, removal efficiencies and removal rates and the difference of HLRs and OLRs were performed using one way ANOVA by SPSS 16.

## 3. RESULTS AND DISCUSSION

### 3.1 Adaptability of the Study Plants

From day 8 to day 15, leaves of (5) became yellow sign and stem became putrescent. Root of (4) was rotten. This phenomenon may be due to submerged condition. Therefore, the height of the original design water level of the model (16 cm) was adjusted to 10 cm. The results showed that when the water level was adjusted to 10 cm, it decreased the phenomenon of yellow-leaf and rotten root.

In the first five weeks, the survival of (2), (3) and (4) reduced by adapting to new living condition. At week 3, the survival rate of (2) and (3) was 88%. At week 4, the survival rate of (4) was 90%. The dead plants were then replaced. It was noticed that (2) and (3) had a rapid growth rate from week 4 and stably adapted throughout the experimental period. The survival rate of (5) from week 16 was 56%.

For (4), although more buds grew on stem (average of 3 buds/tree). The plants were less growth compared to those which were planted on the ground. From week 2, (5) adapted to the system and started to flower quickly. However, from week 12 onwards, the leaves of plant started yellow and wither. The plant (5) belongs to short-term species. In general, among the four plants, (2) and (3) were the best development with conditions of the WR.

### 3.2 Biomass of Plants

The plants were harvested after 124 days growing in the WRs. The fresh and dried plants were weighted. It consisted of stem, leave and root. The capacity of biomass growth according to fresh weight of (2) increased to 442 g (5%); (3) to 1548 g (130%); (4) to 209 g (2%) and (5) to 120 g (1%). In terms of dry weight, (2) increased to 120 g (4%); (3) to 491 g (147%); (4) to 86 g (2%) and (5) to 30 g (1%). This shows that the plant biomass increased in the descending order was (3), (2), (4) and (5). Large amount of water was absorbed into plants (3) and (2).

### 3.3 Treatment Performance of Wetland Roofs

#### 3.3.1 COD removal

The mechanism of COD removal of CW is due to the biodegradation and filtration through media layers. Both aerobic and anaerobic processes reduced 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 the adhesive microorganism layer on submerged body of plant, root system and filter material layer (Tousignant et al., 1999). Nitrogen compounds were also

transformed and uptaked in CW. The principle of organic removal and nitrogen transformation for WR are similar to CW.

At average HLR of 220 m<sup>3</sup>/ha.day (HLR1), from day 47-57, (5) had the highest COD removal efficiency (75%) (Fig. 1b). Day 62 onwards, the efficiency decreased because (5) leaves started to turn yellow-leaf and wither. For the whole operation period, the COD removal in descending order was (3) (70 ± 4% or 30 ± 7 kg/ha.day); (2) (68 ± 5% or 25 ± 5 kg/ha.day); (4) (64 ± 5% or 25 ± 3 kg/ha.day); (5) (65 ± 10% or 23 ± 3 kg/ha.day) and (1) (55 ± 4% or 20 ± 2 kg/ha.day) (Fig. 1a, b). It appears that the control WR removed approximate 55% COD. It can conclude that filter media contributed about 55% COD removal while the plants could achieve 10-15 % COD removal.

At average HLR of 417 m<sup>3</sup>/ha.day (HLR2) (day 83 onward) the treatment efficiency of the plants started decreasing. Although the removal rate increased (Fig. 1a), the concentration of the outlet increased as well. However the treatment efficiency started to decline gradually (Fig. 1b).

In summary, the COD removal efficiency and removal rate of planted WRs were higher than the control one. This shows that the plants could improve organic removal capacity of the WRs. Plants (2) and (3) had the best COD removal efficiency. Furthermore, these plants also had the most rapid growth. It spread and covered the whole area of WR in stable period. Organic matters in wastewater were treated through filter layers and roots of plants.

Form day 47 to day 90, the effluent COD of 42- 96 mg/L satisfied the standard of CITAI (2003) (COD < 100 mg/L) for reusing in the supply of surface water, the regeneration of urban landscape as well as the irrigation for agricultural activities. In addition, the effluent from WRs could also meet the

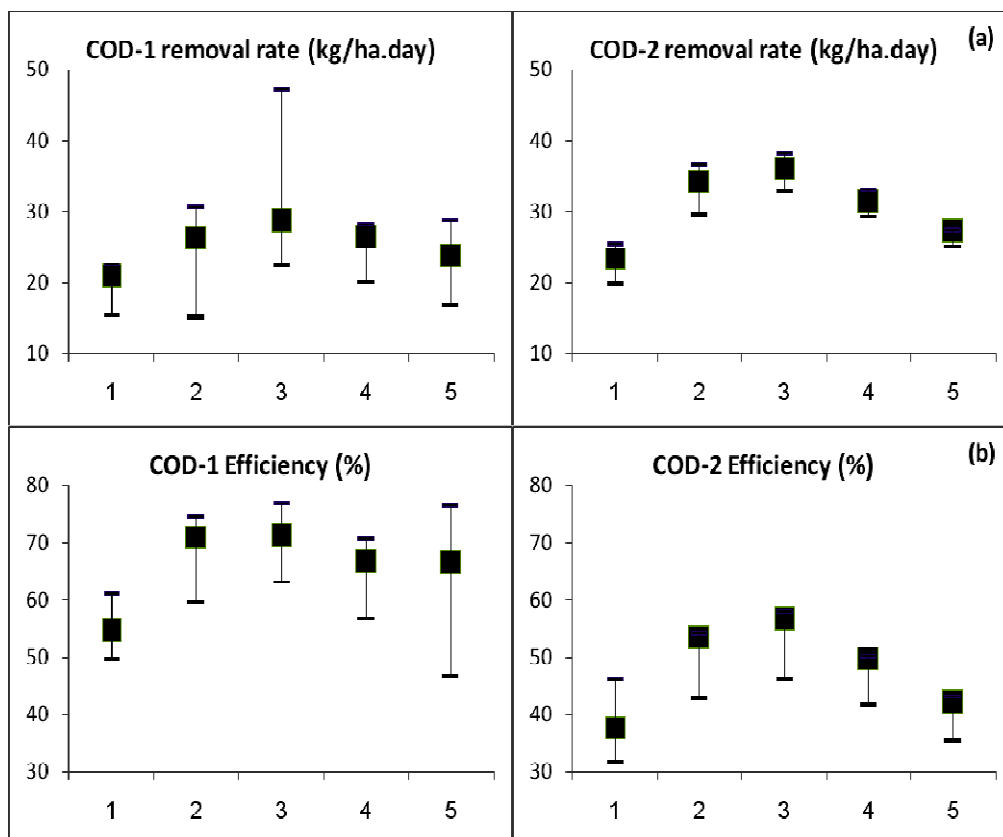
discharge limits for domestic wastewater of Viet Nam (QCVN 14:2008/BTNMT).

### 3.3.2 Nitrogen removal

The concentration of TN in influent wastewater fluctuated greatly. The TN in effluent depended on its concentration in the influent. From day 64-72 (HLR1), the influent TN varied between 17.8 - 19.5 mg/L. The results show the average TN removal efficiencies were  $60 \pm 3\%$ ;  $56 \pm 3\%$ ;  $55 \pm 7\%$ ;  $54 \pm 9\%$  and  $41 \pm 5\%$  for (3), (2), (4), (5) and (1), respectively (Fig. 2). While the average TN removal rates were  $2.5 \pm 0.3$

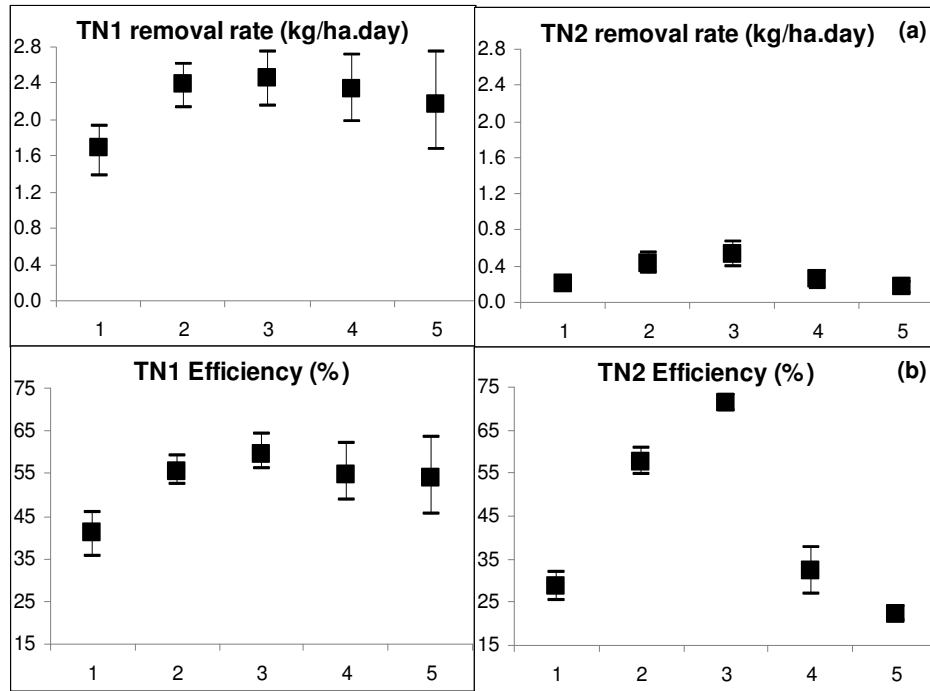
kg/ha.day;  $2.4 \pm 0.2$  kg/ha.day;  $2.3 \pm 0.4$  kg/ha.day;  $2.2 \pm 0.5$  kg/ha.day and  $1.7 \pm 0.5$  kg/ha.day for (3), (2), (4), (5) and (1), respectively (Fig. 2).

From day 85 to day 97 (HLR2), the influent TN concentration decreased significantly (2.2 - 2.5 mg/L). This was due to continuous appearance of heavy rain during this period. The average nitrogen removal efficiency of the plants were  $71 \pm 3$ ;  $58 \pm 4$ ;  $32 \pm 8$ ;  $29 \pm 5$  and  $23 \pm 1\%$  for (3); (2); (4); (1) and (5), respectively. The average TN removal rate was  $0.5 \pm 0.2$ ;  $0.4 \pm 0.2$ ;  $0.2 \pm 0.1$ ;  $0.2 \pm 0.1$  kg/ha.day for (3), (2), (4), (1) and (5), respectively (Fig. 2).



**Figure 1** COD removal rate (a) and COD removal efficiency (b)

**Remark:** Terms “COD-1” and “COD-2” indicate the HLR1 and HLR2, respectively



**Figure 2** TN removal rate (a) and TN removal efficiency (b)

**Remark:** Terms “TN1” and “TN2” indicate the HLR1 and HLR2, respectively

### 3.3.3 Total phosphorus removal

Concentrations of TP also decreased in the control compartment due to the sedimentation of suspended solids containing phosphorus and accumulation in the material layer. This result was similar to the results of Tousignant et al. (1999).

Since day 83 onwards, (2) and (3) were being in the strong developmental period (coverage area achieved almost 100% on day 60). Therefore, the plants required more nutrients to grow. Thus it is observed that the uptake rate of TP was higher. At HLR2, the TP removal efficiency and removal rate were relatively stable. The TP removal efficiencies followed the descending order (3) ( $56 \pm 12$  %); (2) ( $50 \pm 13$  %); (4) ( $44 \pm 15$  %); (1) ( $32 \pm 12$  %) and (5) ( $12 \pm 3$  %). While the TP removal rate was  $17 \pm 6$  g/ha.day;  $16 \pm 6$  g/ha.day;  $13 \pm 6$  g/ha.day;  $8 \pm 3$  g/ha.day and  $4 \pm 1$  g/ha.day for (3); (2); (4); (1) and (5) respectively. The TP concentrations in influ-

ent and effluent were always bellow 0.5 mg/L (Fig. 3)

In conclusion, HLR increased, the results show the removal rate of COD, TP and TN increased. This could be partly due to the fast growth of plants. Additionally, a part of continuous rain (according to recorded results in 5/2011, rainy frequency was 16/31 days which caused a great reduction of the effluent concentrations of COD, TP and TN.

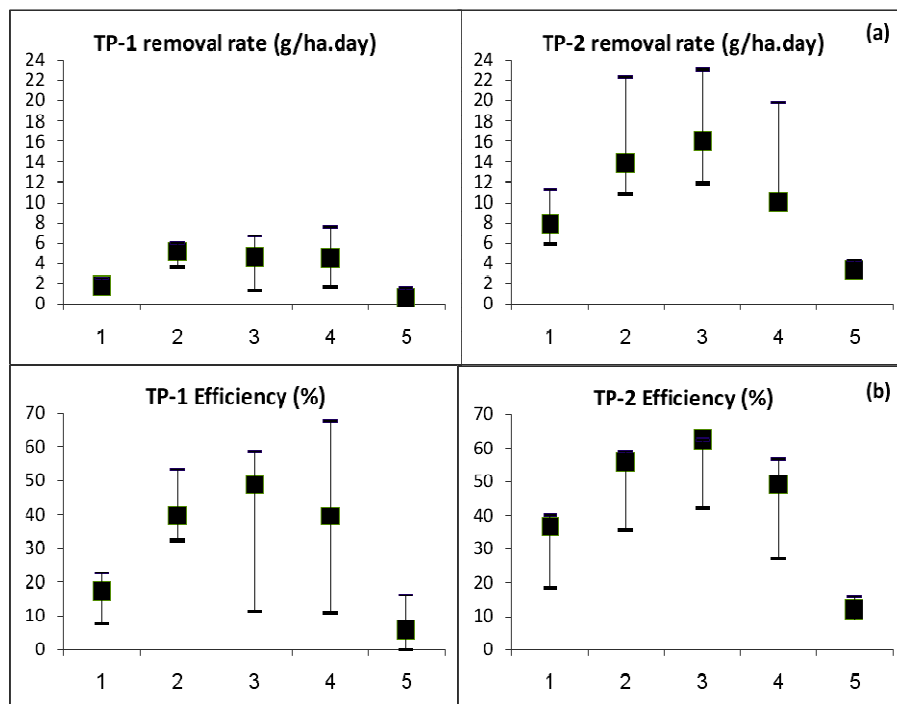
The summary of the treatment performance and characteristics of plants are presented in Table 3.

## CONCLUSIONS

As conclusion, the removal efficiency of (2) and (3) was higher than the other two plants at the average hydraulic loading rate of 220 and 417  $\text{m}^3/\text{ha.day}$ . The removal efficiencies as well as the removal rates were not significant difference between (2) and (3). However the uptake of nitrogen and phosphorus of (3) was

slightly higher than that of (2). In general, *Melampodium paludosum* (3) conformed to the plant selecting criteria than the remaining three plants. In terms of beauty, (5) has the most beautiful flowers compared to the other study plants. Therefore, during the actual deployment, the flower plant could be grown alternating with the main treatment plants to

create the beauty for the wetland roof system. The WR with *Melampodium paludosum* plant could treat domestic wastewater effectively. This system had many benefits on economy, society and environment. The offensive odor and unwanted microorganisms were not observed in the system.



**Figure 3** TP removal rate (a) and TP removal efficiency (b)

**Remark:** Terms “TP-1” and “TP-2” indicate the HLR1 and HLR2, respectively

**Table 3** Treatment performance of plants

Criteria	Adaptability		Removal efficiency at HLR1 (HLR2) (%)		
	Survival rate (%)	Biomass increase (g)	COD	TN	TP
WR					
(2): <i>Axonopus compressus</i>	100	442	68 (50)	56 (58)	41 (50)
(3): <i>Melampodium paludosum</i>	<b>100</b>	<b>1548</b>	<b>70 (54)</b>	<b>59 (72)</b>	<b>40 (56)</b>
(4): <i>Tradescantia spathacea Compacta</i>	100	209	64 (48)	55 (33)	44 (44)
(5): <i>Catharanthus roseus (L.) G. Don</i>	56	120	65 (40)	54 (23)	7 (12)

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