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Performance of wetland roof with *Melampodium paludosum* treating septic tank effluent

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ABSTRACT

Wetland roof (WR) system was developed to apply for building terrace and top roof in the urbanized area of Ho Chi Minh City. This study aims to improve the green area of the city and to treat domestic wastewater through a shallow horizontal subsurface constructed wetland that is located in a household roof. The pilot-scale unit of horizontal subsurface flow WR system with *Melampodium paludosum*, an indigenous emerging plant in Vietnam, was experimented at the average hydraulic loading rate (HLR) of 338 m^3/ha d (~36 kg COD/ha d) corresponding to HRT of 18 h. The treatment performance was not significantly different for rainy and sunny days at various HLRs. It was observed that the average removal efficiency of COD was 77–78% or 20–28 kgCOD/ha d for both sunny and rainy days. It is apparent that nutrient removal was greatly achieved as indicated by TN removal efficiency of 88–91% or 17–20 kg TN/ha d. In addition, TP removal reached 72–78% or 1.6 kg TP/ha d for different HLRs. The treated effluent could comply with the standard limits of Vietnam national technical regulation for domestic wastewater. It was also observed that the growth rate of *M. paludosum* was 0.1 cm/day in length. The ratio between nitrogen uptake by plants over nitrogen removed by WR was 0.13, while the higher ratio of 0.68 was obtained for the case of phosphorus. The temperature of WR units was 4 ± 1°C lower than that on concrete floor that likely help saving energy for building cooling if applying WR on the top roof. Based on the experimental results obtained to date, the WR system would be a promising system for domestic wastewater treatment especially for urbanized city, where green area is of high demand.

Keywords: Wetland roof; *Melampodium paludosum*; Hydraulic loading rate (HLR); Organic loading rate (OLR)

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1. Introduction

Having a green plantation on top roof or terrace of a building is not only beautiful but also environmentally friendly. Many countries are beginning to use green roofs, because a rooftop garden can offset heat, save energy, increase city biodiversity, decrease storm water runoff, and absorb carbon dioxide. One square meter of leaf plants can absorb up to 21 mg CO_2 in 1 min [1]. Over the past 15–20 years, constructed wetland (CW) has been considered particular for municipal wastewater treatment in small communities. The advantages of CW are low-energy requirement, easy in operation, and environmentally friendly [2].

In the developing countries, the sanitation systems based on septic tanks are used for onsite domestic wastewater treatment. This system is low in investment and operation cost, but the treated effluent does not comply with the standard limits of domestic wastewater. The organic removal efficiency of septic tank was only approximately 40–60%. Nutrients (N & P) almost remained in the effluent. Thus, a large amount of pollutant load discharged into water environment causing serious pollution into stream, canals, and rivers in Vietnam [3].

Other studies used types of CWs such as free water surface wetlands, vertical CWs, subsurface CWs to treat the domestic wastewater, and low-strength industrial wastewaters. Further, they can be used as post-treat ment following the secondary biological treatments. Those systems often apply for rural or suburban areas, where land areas are available [2,4,5]. This study aims to develop a simple novel environmentally friendly wetland roof (WR) system coupling with septic tank to improve quality of septic tank effluent and enhance green area in the urban neighborhoods. Furthermore, the green area could also alleviate the effect of carbon dioxide emission such as global warming and climate change.

In this study, a shallow WR system used aster daisy (*Melampodium paludosum*) to treat the septic tank effluent. The treatment performance and growth characteristics of the plant were investigated during the study period in the conditions of rooftop system. The WR system not only offers wastewater treatment, but also contributes to climate change adaptation in Vietnam or other developing countries.

2. Materials and methods

2.1. Experimental setup

A shallow subsurface wetland was set up outdoors under the natural climate conditions in a research station of Ho Chi Minh City University of Technology. The experiments started in mid-July 2011 and lasted for 5 months. The dimensions of experimental system are 1.5 m in length, 0.75 m in width, and 0.3 m in depth (Fig. 1) within which 5 consecutive channels were installed to prevent short circuit of the wastewater flow. The surface area of wetland system was 1.125 m^2. Thickness of media layer from the top to bottom was 10 mm of soil, 20 mm of sand, 120 mm of crush stone, and 50 mm of gravel. The height of water level was 100 mm from the bottom. Wastewater flow rate was controlled by needle valves located in chamber No. 1 and No. 3. Effluent samples were collected after 10 days of plants be transplanted and acclimatized in the experimental units.

Table 1 shows the operating conditions of the WR. Wastewater used was collected from the last chamber of septic tank of a building. The average pollutant concentrations (in mg/L except pH) were 176 ± 43 (COD), 56 ± 14 (TKN), 5.8 ± 0.6 (TP), 63 ± 45 (SS), and 7.9 ± 0.2 (pH).

Aster daisy *(M. paludosum)* was selected to apply in the WR due to its excellent growth in roof top conditions in our previous study [6]. Planting density was 213 trees/m^2. This kind of plant is a wild flower species, locally available, easy to develop with large green surface area. The height of plant is about 20–40 cm, but they can spread out widely. It blooms bright yellow flowers that increases the aesthetic of the treatment zone.

2.2. Sampling and data analysis

During the experimental period, influent and effluent samples were collected three times a week. Samples were taken during the period between 9 and 10 am. The flow rate was measured daily by cylinder, and stopwatch to accurately calculate an average hydraulic loading rate (HLR) in each stage Konnerup et al. [7]. The growth of *M. paludosum* was observed and recorded throughout the experimental period in terms of number of plants, area of

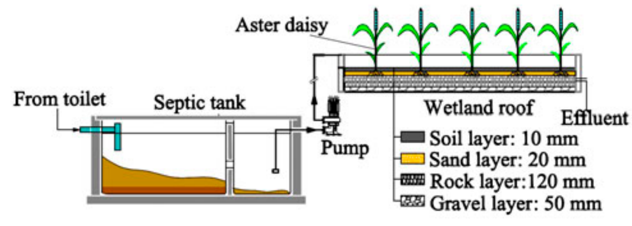

Fig. 1. Schematic diagram of the WR system.

Table 1
Operating conditions of WR system

Stage	HLR (m^3/ha d)	OLR (kgCOD/ ha d)	Flow rate (L/ d)	HRT (h)	Operation (d)
Acclimatization	154 ± 14	21 ± 5	17 ± 2	39 ± 4	47
HLR 1	137 ± 6	24 ± 6	15 ± 1	44 ± 2	26
HLR 2	210 ± 7	28 ± 8	24 ± 1	29 ± 1	26
HLR 3	338 ± 9	36 ± 7	38 ± 1	18 ± 1	26
HLR 4	456 ± 6	57 ± 13	51 ± 1	13 ± 0	26

coverage, and height of plants. At the start-up period and the end of experiment, plant samples were collected and dried at 70℃ until constant weights be achieved and analyzed for total nitrogen (TN) and total phosphorus (TP) concentrations. Analytical parameters include pH, SS, turbidity, alkalinity, color, COD, TP, NH_4–N, and TKN. All samples were analyzed within one day. The analytical methods were according to standard methods [8]. Temperature was measured inside the planted area of experimental units and at the concrete base to compare temperature variation.

At the end of each experimental period (adaptation period and each HLR), aster daisy was harvested and remained only 20 cm of plant height left. The harvested plants were measured both wet weight and dry weight to calculate the biomass growth. The accumulation of nutrients (nitrogen and phosphorus) in plants was calculated for each whole operation period. The concentrations of TN and TP in dry biomass were analyzed to calculate total accumulated nutrients in plant for whole operation period [7]. The average ratio of nutrient uptake by plants was estimated based on the accumulated nutrient in plant over the load of nutrients into system during the operation period as follows:

$$\text{Nitrogen uptake ratio} = (\text{TN}_{\text{accumulated in plants}}) / \left\{ \sum (\text{TN}_{\text{influent}} - \text{TN}_{\text{effluent}}) \times Q \right\} \quad \text{(a)}$$

$$\text{Phosphorus uptake ratio} = (\text{TP}_{\text{accumulated in plants}}) / \left\{ \sum (\text{TP}_{\text{influent}} - \text{TP}_{\text{effluent}}) \times Q \right\} \quad \text{(b)}$$

Comparisons of effluent concentrations, the removal efficiencies and the removal rates between the four HLRs were performed using one way ANOVA by SPSS 16. All variables were tested for normal distribution and variance homogeneity by using Levene's test. Bonferroni was used for Post hoc test comparisons. Significant difference at the 5% level was used in all cases.

3. Results and discussion

3.1. Acclimatization

Aster daisy was planted in the experimental unit that was initially operated at HLR of 154 m^3/ha d (Organic loading rate, OLR of 21 kgCOD/ha d) for 47 days. Removal efficiencies of COD, TN, and TP reached stable values at the end of the acclimatization period. The statistic results show that there was no significant different for removal efficiencies of COD, TN, and TP between sunny days and rainy days. The average removal efficiencies of COD, TN, and TP were 72–82, 78–82, and 82–88%, respectively. The temperature in planted zone was 4 ± 1℃ lower than that at concrete floor. It shows the use of WR made the temperature inside the house reduced naturally.

3.2. Plant growth and nutrient uptake

In the first four weeks, the plants developed their length slowly. From day 28 onwards, it could develop widely and covered entire wetland surface area. One hundred percent of plants were survival during the experimental period. The average growth in length of

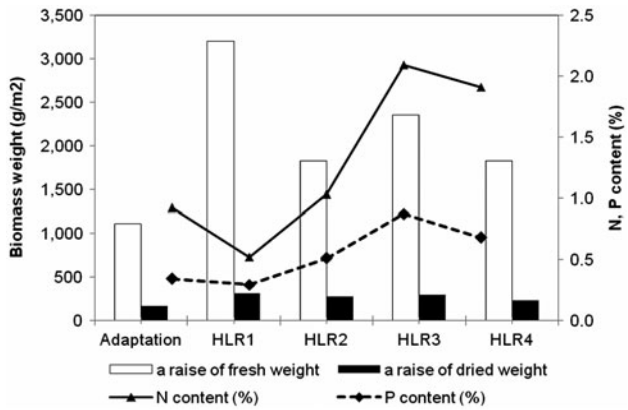

Fig. 2. Mass of *M. paludosum* at different HLRs.

plants was 1.7; 1.4; 1.0, and 1.3 cm/d at HLR1, HLR2, HLR3, and HLR4, respectively. This result shows the length of plants grew faster at the lowest hydraulic loading rate (HLR1) compared with other remaining HLRs (Fig. 2). While the growth rate of common reed was approximately 1.4 cm/d for full-scale CW (Sim et al. [9]).

3.2.1. COD removal

Fig. 3 presents the influent COD concentrations varied from 83 to 292 mg/L during the study. The average effluent COD concentrations were ranging from 25 to 65 mg/L for both rainy and sunny days that were lower than 100 mg/L (Vietnam national technical regulation for domestic wastewater treatment—QCVN 14:2008/BTNMT, level B [10]). The effluent COD concentration was lowest for HLR2 and HLR3. The treated water conformed to the CITAI standard for agricultural irrigation and road cleaning [11].

For sunny days, the COD removal efficiencies were about 53–92%. The highest efficiency was at the HLR2 (79 ± 7%). The HLR1, HLR3, and HLR4 were 65 ± 6, 77 ± 9, and 69 ± 12%, respectively. For rainy days, the COD removal efficiency was ranging from 60 to 91%. The highest one was also at the HLR2 (84 ± 6%). The HLR1, HLR3, and HLR4 were 73 ± 11, 78 ± 4, and 78 ± 9%, respectively. In general, the COD removal efficiency of the rainy days was slightly higher than those of the sunny days. This was due to the dilution effect of rain water. Similarly to the acclimatization period, the statistical results showed no significant

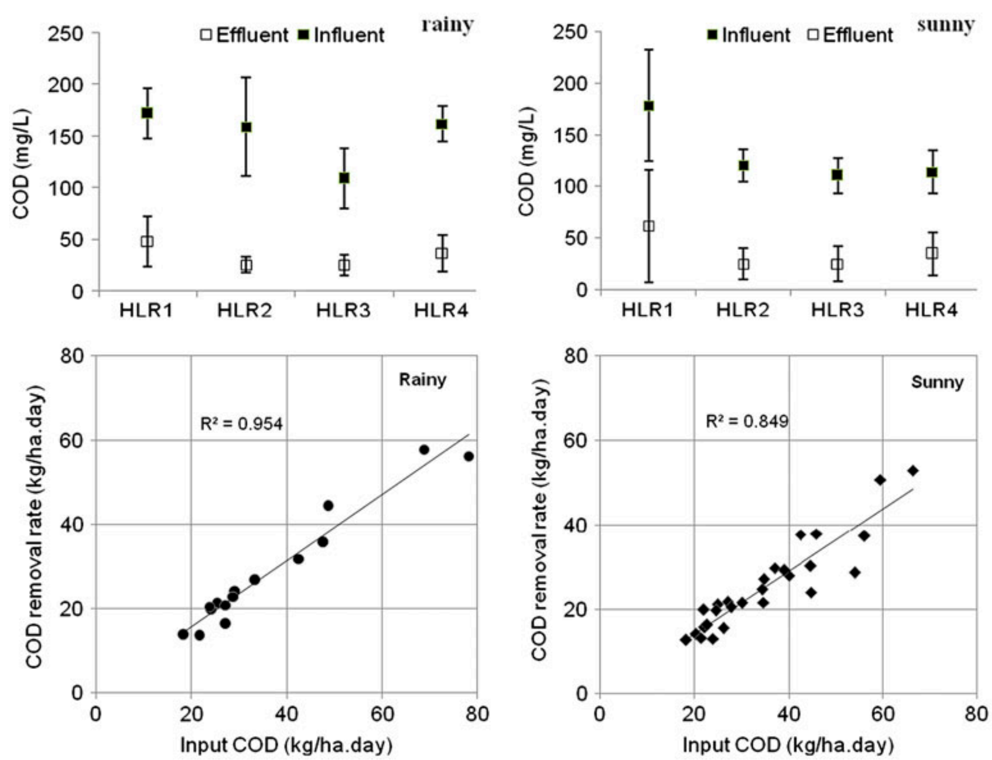

Fig. 3. COD concentrations (above) and correlations of input COD loading rate vs. removal rate (below) in WR.

difference at 5% level of the removal efficiencies between sunny days and rainy days.

The average COD removal rates of HLR1, HLR2, HLR3, and HLR4 of sunny days (rainy days) were 16 ± 5 (17 ± 4); 20 ± 2 (28 ± 11); 29 ± 7 (28 ± 6); and 36 ± 11 (57 ± 1) kg COD/ha d, respectively. The HLR4 shows the highest removal rate and significant difference at 5% level.

3.2.2. Nitrogen removal

Nitrogen removal in conventional CWs occurs through adsorption, assimilation into microbial and plant biomass, ammonia volatilization and simultaneous nitrification and denitrification [5,12]. The ammonia volatilization was probably very low as the pH was in the range of 6.9–7.4 [13]. For CW environment, as the depth layer of material deeper dissolved oxygen reduced gradually. This creates good conditions for denitrification. In this study, the influent TN concentration fluctuated between 30 and 81 mg/L for four HLRs. The effluent TN concentrations (excepted HLR4) was less than 10 mg/L (Fig. 4) which conformed to the Vietnamese standards (QCVN 14:2008/BTNMT, level B) and Jordan water reuse standard for artificial groundwater recharge (⩽30 mg/L), and for recreation area and industrial crops (⩽45 mg/L) [14]. This indicates the suitable HLR for aster daisy was less than 338 m^3/ha d (HLR3).

Fig. 4 reveals at HLR2, HLR3, and HLR4 the removal efficiencies as well as the removal rates of TN on rainy days were greater than or equal to those on sunny days. This was due to the effect of rain water dilution. It appears the average TN removal rate at HLR3 was the highest. It was 17 ± 6 kg/ha d (sunny days) and 20 ± 5 kg/ha d (rainy days). There was only significant difference between other HLRs and HLR1. The TN removal reduced at HLR4 because the hydraulic retention time of the system decreased. The simultaneous nitrification denitrification process could not occur at the operating conditions. The mass balance for WR system shows that the ratio between nitrogen uptake by plants over the nitrogen removed was 0.09; 0.10; 0.13, and 0.11 for HLR1, HLR2, HLR3, and HLR4, respectively. The results show the nitrogen uptake capacity of aster daisy reached critical level at HLR of 338 m^3/ha d.

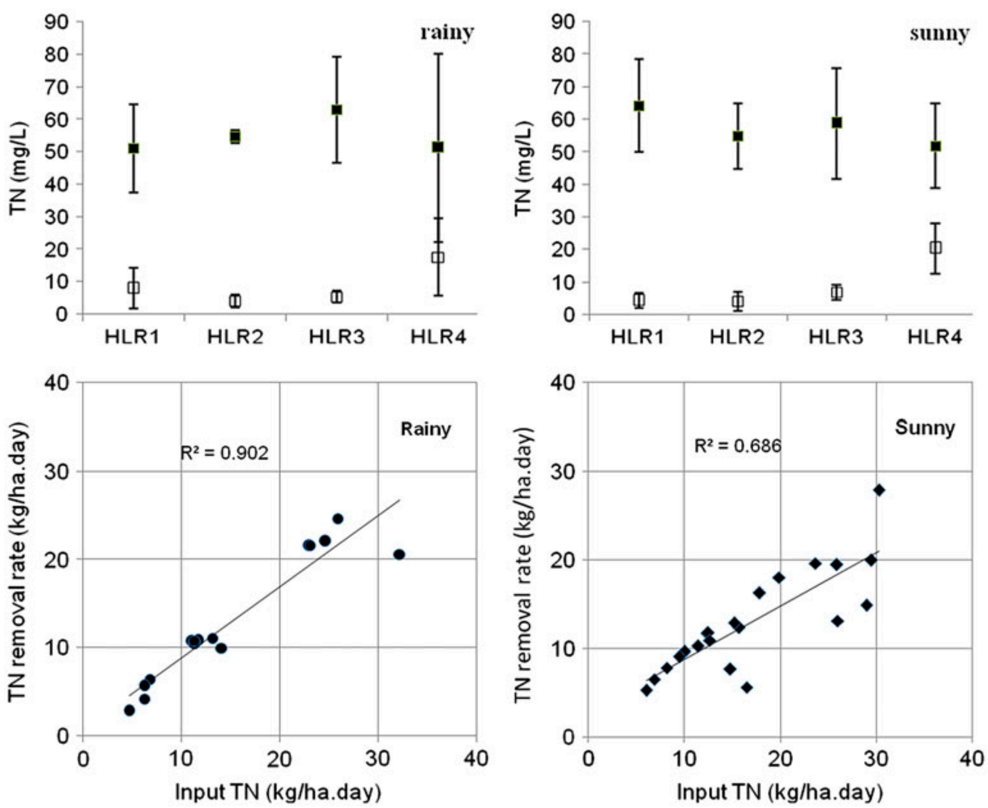

Fig. 4. TN concentrations (above) and correlations of input TN loading rate vs. removal rate (below) in WR.

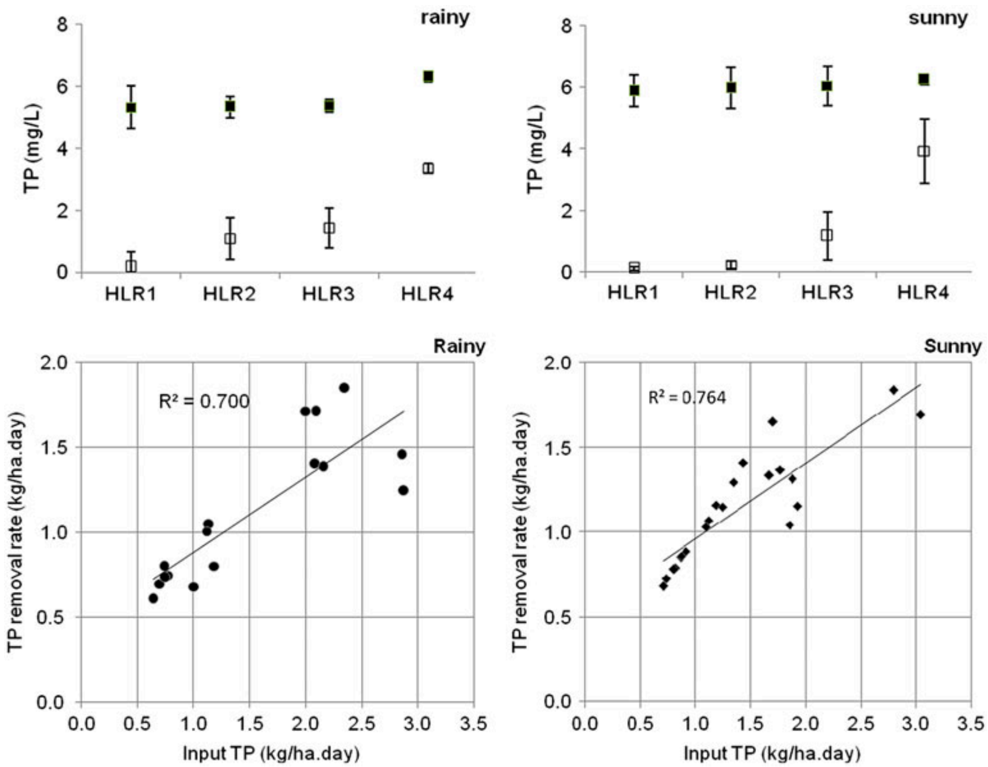

Fig. 5. TP concentrations (above) and correlations of input TP loading rate vs. removal rate (below) in WR.

3.2.3. Phosphorus removal

The major processes responsible for phosphorus removal in horizontal subsurface flow CWs are assimilation into microbial and plant biomass, adsorption to medium and precipitation with metal ions (Cooper et al. [4]).

Fig. 5 shows influent TP concentration varied between 1.3 and 7.0 mg/L. On sunny days as well as rainy days, effluent TP concentrations were less than 5 mg/L that was below the allowable threshold of the level B, QCVN 14:2008 standard (⩽10 mg/L). According to the CITAI (2003), TP in water reuse for irrigation is lower than or equal 2 mg/L. The water reuse standard of Ho Chi Minh City for regenerating landscape with TP is lower than or equal to 6 mg/L [14]. The treated effluent of WR at HLR1, HLR2, and HLR3 satisfied this purpose.

The TP removal efficiency gradually decreased with an increase in HLR. The TP removal rate increased gradually from HLR1 to HLR3 and reduced strongly at HLR4. The highest phosphorus removal rate of 1.8 kgP/ha d was at HLR3. The mass balance for WR system shows that the ratio between phosphorus uptake by plants over the phosphorus removed was 0.47; 0.50; 0.68, and 0.53 for HLR1, HLR2, HLR3, and HLR4, respectively. Similar to nitrogen mass balance, the phosphorus uptake capacity of plants reached the maximum at HLR3. The statistic results confirm the removal rate at HLR3 showed significantly higher than other HLRs for sunny days. The rainy days were mostly affected by dilution phenomena.

Table 2 indicates COD and SS removal in the WR was lower than the conventional wetlands. Most researchers reported that conventional CWs were efficient in solids and organic matter removal but less efficient in nutrient removal [12,15]. The removal rate of SS in the report of Kadlec and Knight [16] was higher than that was due to the higher applied SS loading rate. The average concentration of SS in this study was as low as 63 ± 45 mg/L which comes from the third chamber of a septic tank. It is interesting that the nutrient removal efficiency in the study WR was found to be greater than that in the conventional wetlands. This can be explained that the thick media layer in conventional wetlands (commonly 500–600 mm depth) accumulated more bacteria, thus more degradation of organic matters. The removal of nitrogen and phosphorus depends on the plant uptake. Vymazal [5] noticed that desirable traits of a plant used for nutrients assimilation and storage includes rapid growth, high tissue nutrient content, and the capability to attain a high standing crop. The aster daisy shows

Table 2
Comparison between WR and conventional (reed/gravel bed) wetlands

Parameters	COD	NH_4^+–N	TKN	TP	SS
Removal efficiency (%):					
This study	*71*	*98*	*92*	*74*	*95*
Kadlec and Knight [16]	nd	9	61	22	74
Koukia et al. [17]	89	nd	38	72	nd
Yang et al. [18]	80	72	75	80	nd
Removal rate (kg/ha d):					
This study	*28*	*16*	*19*	*1.4*	*12*
Kadlec and Knight [16]	nd	0.62	5.85	0.12	35
Vymazal [5]	nd	nd	9–23	1.6–2.7	nd

Note: nd—not determined.

their excellent in nutrient uptake compared with reed or cattails. Thus, the WR with aster daisy is an effective solution for eutrophication control in the tropics.

In general, almost all the reed/gravel bed systems reported for treating household primary effluent have achieved higher BOD_5 and SS reductions, at relatively low HRT's, than nutrients that have required higher HRT's. The conventional reed/gravel beds with a 500–600 mm soil/aggregate depth are responsible for the higher BOD_5 and SS removal in literature findings. While the shallow bed of 200 mm and water depth of 100 mm in this designed WR are probably accounting for the very good COD, SS, and nutrients reduction results.

4. Conclusions

This study confirms that shallow horizontal subsurface flow WR system with *M. paludosum* (Aster daisy) can effectively improve quality of septic tank effluent in the tropical countries. The ratios between nitrogen uptake by plants over the nitrogen removed were 0.09; 0.10; 0.13, and 0.11 for the HLR1, HLR2, HLR3, and HLR4, respectively. The ratios of phosphorus were 0.47; 0.50; 0.68, and 0.53 for HLR1, HLR2, HLR3, and HLR4, respectively. The HLR of 338 m^3/ha d (HLR3) was found to be the most suitable for the shallow media WR (20 cm depth) with aster daisy (Note—this is shallow compared with reed/gravel bed systems). The average removal rates of COD, TN, and TP were 29, 17, and 1.8 kgP/ha d, respectively. The WRs system with aster daisy was found to be effective in nutrient removal but less efficient in organic matters and solids. The treated effluent could meet the Vietnamese standards for discharge into surface waters and the reuse water standards. The promising results from this study would contribute to stimulate to a broader use of WR systems as a robust, cost-effective, and reliant green roof systems in Vietnam and other tropical countries. Therefore, WR is the one of solutions to reduce carbon dioxide emissions in urban areas as well as effects of climate change.

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