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Improvement of septic tank effluent and green coverage by shallow bed wetland roof system

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A B S T R A C T

This study investigates the wastewater treatment performance of four local plant species in wetland roof systems (WRs). The tested species include *Cyperus Javanicus Hot* (WR1), *Eleusine Indica (L.) Gaertn* (WR2), *StruchiumSparganophorum (L.) Kuntze* (WR3) and *Kyllinga Brevifolia Rottb* (WR4). The plant growth rate, nutrient uptake, wastewater treatment performance and leaf coverage were investigated. The WRs were operated at hydraulic loading rates of 353–403 m^3 ha^{-1} day^{-1}. As a result, WR4 achieved the highest biomass growth of 73.7 g day^{-1} (fresh weight) or 12.0 g day^{-1} (dry weight). The nutrient accumulation of WR4, according to dry biomass, was 1.7% of total nitrogen (TN) and 0.05% of total phosphorus (TP). The highest COD and TN removal rates (33 ± 10 kg COD ha^{-1} day^{-1} and 14 ± 4 kg TN ha^{-1} day^{-1}, respectively) were also recorded in WR4. There was statistically insignificant difference in TP removal rates (0.4–0.5 kg ha^{-1} day^{-1}) among WRs. In terms of green leaf area coverage, WR1 and WR4 also introduced extremely high specific green leaf area as 98 and 99 m^2 of green leaves per m^2 of wetland area, respectively. Subsequently, WR1 and WR4 performed better than others in a range of benefits providing green area and treating septic tank effluent.

1. Introduction

At the beginning of the 20th century, about 54% of the world population lives in urban areas and a proportion is predicted to increase to 66% by 2050 (United Nation, 2014). It means that the world's population is on increased trend in the urban with more than half living in the urban cities. Due to the recent global situation, the urban environmental problems have gained concerns associating to urban planning, population explosion, narrowing of green spaces, human health, risk of pollution, urban storm management, etc. In principal, the rising pollution causes many negative impacts such as decreasing biodiversity, deteriorating mental and physical health, food and water insecurity and last but not least, declining green space. Several cities have been making plans to preserve their natural environment by designing and utilizing vegetated green area as open spaces or parks to serve the public. As the number of urban cities in the world continue to grow along with the population explosion, continuing value green spaces is vital but also a challenge for policy makers, practitioners and communities. Moreover, more serious issues would happen in developing nations where they might face to pressure of space, resource development and general management. Thus, consideration about green spaces in urban areas has the potential to access to further sustainable development relating to human health, environment, land use, etc.

Therefore, research in these emerging fields are now being undertaken by several sectors such as urban planning and design,

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environmental study and, especially the integration between urban green space and environmental aspect so-called green roofs (GRs). Further, they have gained more interested in spontaneously vegetated roofs and began to design a green roof since they were invented. Moreover, the constitution of green roofs offers several benefits in the comparison to conventional roofs due to the fact that the integration is established between environmental and urban planning issues (US GSA, 2011).

For instance, GRs function very well since they supply multiple advantages such as improving environmental quality, reduction of noise pollution, sustainable drainage and storm water amelioration, thermal stability-cooling, better visual aesthetics, biodiversity, control of air pollution by reducing smog and airborne particles and management of runoff rain water (Berndtsson, 2010; Song et al., 2013). GRs increase spaces for vegetation and animal biodiversity in cities and reduce a city's carbon footprint by converting carbon dioxide to oxygen through photosynthesis (Li et al., 2010; Rowe, 2011). In addition, a green roof is also beneficial in saving energy and decreasing of the urban heat island (Wong et al., 2003; Wanphen and Nagano, 2009). Especially, GRs help to reduce the pollutants in rain water. Berndtsson et al. (2006) found that average total nitrogen (phosphorus) concentration in rainwater was reduced 13% for the extensive roof and 78% (75%) for the intensive roof. Furthermore, GR also has the ability to retain heavy metals in rainwater. For instance, Steusloff (1998) reported that an extensive grasses-GR could retain Cu, Zn, Cd and Pb more than 90% in summer time and were lower in winter time as 44%, 72%, 62% and 91%, respectively. In another study carried in Sweden, Cr, Mn, Pb and Zn was announced to retain 61%, 24%, 93% and 8%, respectively (Berndtsson et al., 2006).

Nowadays, constructed wetland (CWs) has recently been well-known worldwide as a wastewater treatment technology operating in natural conditions, environmentally friendly, high removal efficiency, low cost and stability; meanwhile, it also contributes to the value of biodiversity (Vymazal, 2007; Saeed and Sun, 2012; Shao et al., 2014; Wu et al., 2016). Horizontal subsurface flow CWs can successfully treat wastewater with very low concentrations of organics (BOD < 50–80 mg l^{-1}) which cannot be treated by conventional treatment systems such as activated sludge (Vymazal, 2009). Horizontal subsurface flow CWs is suggested to apply in developing countries because it is one of the simplest and low cost technologies (Carballeira et al., 2017). The treatment performance of domestic wastewater by horizontal subsurface flow CWs was reported as 63–94% for COD, 39–70% for TN, 21–74% for NH_4^+-N and 41–96% for TP (Luederitz et al., 2001; Vymazal and Kröpfelová, 2008; Zurita et al., 2009). On the contrary, one of the disadvantages of CW is to require a large area which is not applicable in urban areas because of limit of land resources. Due to this reason, it is essential to integrate the wetland with a sector that can both create green areas for a building and treat domestic wastewater as well. As a consequence, wetland roof (WR) system can be considered as an innovative combination of GR and CW. Another study about household scale WR in Israel, grey water used as substrate was fed to WR to evaluate not only wastewater treatment efficiency, but also effect of energy saving during hot and humid climate (Cynthia (2016). In South Korea, there was a CW model conducted on the roof of a six-story building in Seoul National University showed that the practical temperature of the roof was reduced and more stable compared with conventional roofs due to macrophyte plant evaporation of 1700 l m^{-2} (Song et al., 2013). Excluding from heat reduction, those specific species as *I. laevigata* and *I. pseudoacorus* were assessed to tolerate drought and flooding.

Eventually, there is a lack of previous studies about pollutants removed by WR from wastewater. In our previous studies implemented in the tropical climate of Vietnam, there were some developments of a horizontal subsurface flow shallow bed WRs cultivated with specific local plants such as *Melampodium Paludosum*, *Cyperus Alternifolius,* etc. As obtained results, the WR system achieved the COD, TN and TP removal efficiency of 77–78%, 88–91% and 72–78%, respectively (Thanh et al., 2014). The effects of different types of plant were also investigated, then, *Cyperus Alternifolius* was found to be optimal among the study plants since the best achievement of nutrient removal such as TP and TN removed by plant were 89% and 92%, respectively (Van et al., 2015).

This study is aimed to assess the performance of WRs in terms of wastewater treatment located in Ho Chi Minh city under the tropical climate. Optional parameters were analyzed such as water quality, plant biomass, nutrient assimilation and increase in urban green area. There were four different species of plant selected for this study as *Cyperus Javanicus Hot, Eleusine Indica (L.) Gaertn, Struchium Sparganophorum (L.) Kuntze* and *Kyllinga Brevifolia Rottb* technically denoted WR1, WR2, WR3 and WR4, respectively. Recent integration was proposed to enhance dual advantages of wetland roofs in wastewater treatment and green area in the urban.

2. Materials and methods

2.1. Experimental setup

The experiments were conducted in four pilot-scale shallow bed WR systems. The dimensions of each channel were 1.8 m × 0.2 m × 0.15 m (length × width × depth). The bed layer from top to bottom was composed of 5 mm of soil, 95 mm of sand and 20 mm of a small rock. Gravel layer was placed with the thickness of 100 mm at two endpoints of each system for ease of water distribution and collection. The wetland with a higher aspect ratio (length to width) and lower water depth respected to higher pollutant removal efficiencies (García et al., 2005). Each system was separated into three consecutive channels to create plug-flow conditions and increase the aspect ratio (9:1). The water depth of 100 mm was maintained by a needle valve installed at the outlet pipe. The inlet pipe was designed as horizontal subsurface flows to limit the issues of nuisance odor and vectors and more suitable for applying behind a septic tank effluent (Jácome et al., 2016). Those systems had the slope of 1%.

The mass load of WR system was approximately 163 kg m^{-2}. The WR models were located in the open area inside university campus (10°46′31.3″N, 106°39′35.2″E). This position was a wide-open area so that those models were suffered with natural conditions as sunlight, wind and rain. This research was undertaken in the period of August 2014 to July 2015. About climatological indicator of HCMC, the average temperature was in the range of 28.4–28.7 °C; sunshine hours were 2382 h and the precipitation were 1883–2042 mm (HCMSO, 2016)

Initially, the WR systems without plants were supplied with tap water for 30 days to stabilize the bed layers. Then, the selected plants were cultivated in the WR systems and sprinkled with tap water for 10 days. In the 30 days following, the systems were fed with wastewater from the septic tank effluent to provide nutrients for plants and microbial growth. The adaptation of the plants under WR condition was observed. The wastewater samples were not collected during this period. In reality, for further application of WR technology in the future, the height of the selected plants should be controlled to prevent mosquito and effects of wind. Therefore, the experimental plants were cut in advance to remain height/length above the soil surface about 20 cm before feeding with wastewater. For parameters analysis, samples collected from inlet and outlet were determined to investigate the efficiency of WR systems for 61 days. The operating conditions of those systems are displayed in Table 1.