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Effects of Substrate Types on Runoff Retention Performance Within the Extensive Green Roofs

[1, 2]M.F. Chow, [2]M.F. Abu Bakar, [1, 2]L.M. Sidek and [1, 2]H. Basri
[1]Center for Sustainable Technology and Environment (CSTEN),
[2]Department of Civil Engineering, College of Engineering, Universiti Tenaga Nasional,
Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Kajang, Malaysia

Abstract: Little is known about the water retention performances of different substrate types within extensive green roofs in Malaysia. Thus, this research focused on the runoff retention performance within extensive green roof system with respect to different substrate types in Malaysia. A total of six green roofs were constructed with four being vegetated and two left unvegetated with bare soil acted as control. Four test beds were vegetated with *Axonopus compressus* (cow grass) and *Portulaca grandiflora* cultivars (sedum) in both pot soil and burn soil, respectively. The runoff volume was measured volumetrically through connected to an surface runoff harvesting tank under the test beds. Water retention was calculated from the difference between rainfall and runoff volumes from each test bed. Results showed that burn soil was the most effective substrate type in retaining runoff water. The test bed with sedum planted in burn soil performed the best runoff retention efficiency in extensive green roof system in Malaysia.

Key words: Green roof, hydrological performance, runoff retention, substrate type, tropical, Malaysia

INTRODUCTION

In 2012, a study showed that Kuala Lumpur's green areas have been reduced to 59.4% or 14,386 ha from its original 24,222 ha of city area (Yusof and Johari, 2012). The level of urbanization is rising and expected to reach 83% in 2030 UN (United Nations), 2002. This showed that the urbanization process had affected the Kuala Lumpur's green areas, thus creating many environmental problems and creating high demand for its urban green spaces (Abdul, 2012). Development entity such as street, driveways as well as buildings have been replacing forests, grassland, tree and others that will cause increasing volume of storm water runoff, diminishing ground water recharge, river erosion as well as enhancing stream channel (Stone, 2004). As additional impervious surface are created, there is an increase in storm water runoff and anthropogenic pollutant that are responsible for urban aquatic environmental problems (Carter and Rasmussen, 2005). Futhermore, climate change and variability have caused significant impacts on hydrological cycle (floods and droughts) as well as affecting the overall level of water availability in urban city (Ghahraman, 2013; Khordadi *et al*., 2015; Dariane, 2003). Quantity and quality control at sources in urban area is one of main approach in storm water management (Department of Irrigation and Drianage, 2000). The concept of green roof nowadays has increasingly popular as it brings many benefits toward the environment and promoting sustainable lifestyle (Moran *et al*., 2003; Chow *et al*., 2015). Green roofs can reduce the energy consumption by decreasing cooling and heating loads (Saadatian *et al*., 2013; Kamarulzaman *et al*., 2014), provide amenity and aesthetic value increase building values, improve stormwater runoff mitigation (Liptan, 2003; Kok *et al*., 2016; Kasmin *et al*., 2014; Chow *et al*., 2015), lower air temperatures (Shaharuddin *et al*., 2011), enhance urban air quality assist in urban stormwater pollutant removal, reduce noise in urban environments and mitigate urban heat island effects. Green roof technologies are the integrated knowledge of plants biology, hydrology and architecture. Designing the green roof required a good knowledge of engineering as all the critical aspects of design must be included such as weight of the systems, suitability of proposed plants and the environmental aspect at the regions. Commonly, the green roof consists of two layers, the vegetation and growing media or substrate for vegetation grows (Dunnett and Kingsbury, 2004). The good substrate layer must be efficient in retaining and absorbing the water to achieve the purpose of building green roof is to be water retention medium. This study was aimed to determine the runoff water retention efficiency of different substrate types within extensive green roof system in Malaysia.

Corresponding Author: M.F. Chow, Center for Sustainable Technology and Environment (CSTEN), Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Kajang, Malaysia

Fig. 1: Experimental green roof test beds at the rooftop level of College of Engineering, UNITEN

Developing the extensive green roof under tropical climate like Malaysia is a challenge because it needs to study the suitable native plants species that can endure the harsh environment of tropical climate. Therefore, there must be research conducted as the way to promoting sustainable lifestyle in Malaysia.

MATERIALS AND METHODS

This study was conducted at the rooftop level of College of Engineering in Universiti Tenaga Nasional (UNITEN). Four test beds which vary systematically in their substrate and plant types were established at the study site in October, 2015 (Fig. 1). Each test bed is 0.8 ×0.5 m (length×width), installed at height of 0.8 m from ground level. Two test beds of pot soil were vegetated with *Axonopus compressus* (cow grass) and *Portulaca grandflora* cultivars (sedum) while another two test beds with the same plant species were planted in burn soils. The depth of each type of soil is 150 mm. The number of plants in each test bed was determined by plant species size and proximity to which 100% cover was to be expected by the end of the growing season. To maintain species composition, any plants not planted that germinated in the module were removed by hand once or twice a month during the study period. Two test beds with no vegetation (bare ground) were also prepared for each type of substrate as a control. Data collection was conducted in March, 2016 for accessing the effect of substrate types on stormwater runoff retention performance. Rainfall and temperature data were collected from a weather station which installed at the study site. Runoff were measured volumetrically through connected to an infiltrated runoff harvesting tank under the test beds. Water retention was calculated from the difference between the rainfall and runoff volumes from each test bed.

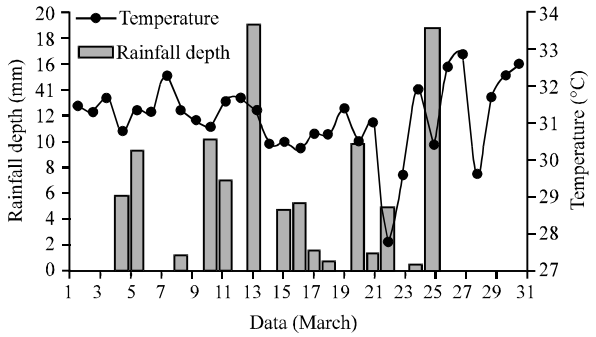

Fig. 2: Monitored storm events and daily mean temperature during the study period

RESULTS AND DISCUSSION

Monitored storm events: The daily rainfall depth and temperature at the study site was monitored during the study period. A total of sixteen storm events were recorded at the study site. The highest rainfall depth is on 19th and 25th March which recorded a total of 19 mm. On the other hand, storm event on 20th March has the lowest rainfall depth which is only 0.2 mm. The mean rainfall depth for storm events during the monitoring period is 6.3 mm. The daily mean air temperature did not vary greatly throughout the study period, except on 22th March and 28th March (Fig. 2).

Soil characteristics: Pot and burn soils were investigated for its water retention performance in extensive green roof system. The particle size distributions for both soil types are plotted as shown in Fig. 3. The particles in pot soil were mostly formed by the size of 425 um which account for 58.68% of total soil weight. Meanwhile, the particles in burn soil were mostly formed by the size of 150 um which account for 61.58% of total soil weight. The particle size of pot soil is finer than burn soil where the particle size <2 mm contributes 95.22% of total soil weight. On the other hand, particle size <2 mm in burn soil is only contributing 88.74% of total soil weight. The physical characteristics for both soil types were determined and summarized in Table 1. The pot soil is consists of high water content, low organic content and high void ratio. Inversely, burn soil exhibits higher organic content, higher maximum water holding capability but lower in void ratio. Both soil types have shown significant different in their physical properties.

Water retention efficiency analysis: The amount of rainfall and runoff volumes from each test bed in this study is summarized in Table 1. The results showed that the green roof test beds were able to retain all rain water

Table 1: Physical characteristics of pot and burn soils

Parameters	Pot soil	Burn soil
Organic content (%)	6.33000	29.65000
Permeability of soil, k (mm/sec)	0.00075	0.00118
Specific Gravity (Gs)	1.70000	1.23000
Density of soil (Full saturation) (Mg/m^3)	0.51900	0.31200
Dry density of soil, pd (Mg/m^3)	0.09500	0.18400
Void ratio, e = ((Gs×Pw)/Pd)-1	16.89500	5.68500
Porosity, n = (e /(1+e))	0.94400	0.85000
Water content (w)	0.14800	0.21900
Maximum water holding capacity, Sr = (wGs)/e	0.01500	0.04700
Air voids content Av = (e-wGs)/1+e	33.53800	11.10000
Particle density, Mw = Sr e Pw	0.25100	0.26900

Table 2: Amount of water retention by different test beds with pot and burn soils

			Runoff volume collected from test bed (L)					
			Pot soil		Burn soil		Pot soil	Burn soil
Date (March)	Rainfall depth (mm)	Rainfall volume (L)	A1 (Grass)	A2 (Sedum)	B1 (Grass)	B2 (Sedum)	C1	C2
4	5.8	2.32	0.00	0.00	0.00	0.00	0.00	0.00
5	9.3	3.72	0.73	0.60	0.67	0.58	1.02	0.98
8	1.2	0.48	0.00	0.00	0.00	0.00	0.00	0.00
10	10.1	4.04	0.78	0.62	0.74	0.58	1.24	1.24
11	7.0	2.80	0.00	0.00	0.00	0.00	0.00	0.00
13	19.0	7.60	N/A	N/A	N/A	1.12	2.19	1.98
14	0.2	0.08	0.00	0.00	0.00	0.00	0.00	0.00
15	4.7	1.88	0.00	0.00	0.00	0.00	N/A	N/A
16	5.3	2.12	0.00	0.00	0.00	0.00	N/A	N/A
17	1.6	0.64	0.00	0.00	0.00	0.00	0.00	0.00
18	0.7	0.28	0.00	0.00	0.00	0.00	0.00	0.00
20	9.8	3.92	0.77	0.62	0.73	0.60	1.18	1.28
21	1.4	0.56	0.00	0.00	0.00	0.00	0.00	0.00
22	4.9	1.96	0.00	0.00	0.00	0.00	0.00	0.00
24	0.5	0.20	0.00	0.00	0.00	0.00	0.00	0.00
25	18.9	7.56	N/A	N/A	0.93	0.65	1.11	1.23

amounts when the rainfall depth is <7 mm. The bare soil test beds showed the least capable to retain the rain water during the study period. There is no significant different on the runoff retention performance by pot and burn soils test beds where both soils exhibited similar rainwater retention percentage of 73%. It was shown that vegetation had a great influence on the amount of retained rainwater. The monoculture of sedum in burn soil is more effective at reducing the water runoff by averagely retaining 86.3% of runoff water. The average percentage of runoff water retained by grass planted in pot soil was least capable to retain the rainwater which only performed 80.5% of retention percentage. Overall, the test bed of sedum planted in burn soil was the most effective combination at reducing water runoff. Simmons found that green roofs retained all small rain events that were <10 mm. The retention of green roofs differed from 88-26% when the rain events were 12 mm but such retention was depended on the substrate and the type of drainage. Getter *et al*. (2007) investigated the organic matter content and physical properties of soil in green roof system after 5 years of time. They found that the organic matter content was increased from 2-4% and the pore space was also increased from 41-82%. Along with that, the water

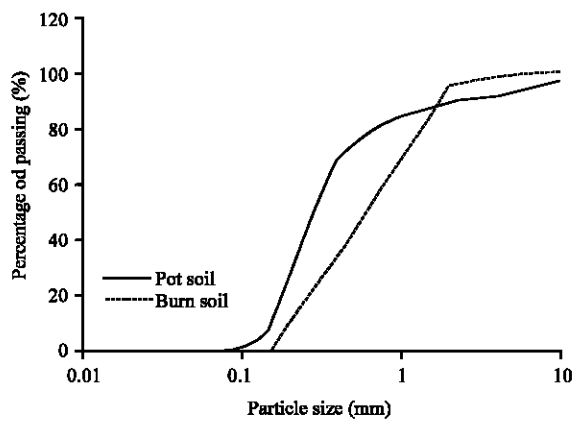

Fig. 3: Particle size disribution of pot and burn soils used in green roof test beds

holding capacity was also increased from 17-67%. Yio *et al*. (2013) also found similar finding that runoff detention increases with increasing substrate organic content in green roof. Therefore, it can be concluded that substrate with high organic content is able to improve the water retention ability of extensive green roofs (Table 2 and 3).

Table 3: Percentage of water retention by different test beds with pot and burn soils

	Percentage of retain (%)					
	Pot soil		Burn soil		Pot soil	Burn soil
Date (March)	A1 (Grass)	A2 (Sedum)	B1 (Grass)	B2 (Sedum)	C1	C2
5	80.4	83.9	82.0	84.4	72.6	73.7
10	80.7	84.7	81.7	85.6	69.3	69.3
13	N/A	N/A	N/A	85.3	71.2	73.9
20	80.4	84.2	81.4	84.7	69.9	67.3
25	N/A	N/A	87.7	91.4	85.3	83.7
Mean	80.5	84.2	83.2	86.3	73.7	73.6

CONCLUSION

The results in this study have shown the runoff retention performance of two substrate types within the extensive green roofs in Malaysia. Based on the findings in this study, it is proved that different types of substrates have their own ability in retaining runoff water within extensive green roofs. The monoculture of *Portulaca grandiflora* cultivars (sedum) in burn soil has proved that it performed the best runoff water retention efficiency for extensive green roof system.

RECOMMENDATION

Further research on other types of substrates and plant species is necessary in order to find the ultimate substrate and plant species that have the best hydrological performance for extensive green roofs in tropical country.

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