International Journal of High-Rise Buildings
December 2014, Vol 3, No 4, 1-6

International Journal of
High-Rise Buildings
www.ctbuh-korea.org/ijhrb/index.php

Influence of Low Growing Vegetation in Reducing Stormwater Runoff on Green Roofs

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Abstract

Green roof's performance in reducing stormwater runoff has been reported by numerous studies. Nonetheless, the roles of low growing vegetation in influencing stormwater runoff reduction on green roofs have been greatly overlooked. This paper describes an experiment investigating the influence of low growing vegetation in the reduction of tropical stormwater runoff on extensive green roofs. Three types of locally occurring native vegetation and one non-native Sedum species were selected (fern, herb, grass and succulent) for the experiment. Stormwater runoff reduction performance from different low growing species was done by measuring excess water runoff from the simulated green roof modules. The results show significant differences in stormwater runoff reduction from different types of vegetation. Fern was the most effective in reducing stormwater runoff, followed by herb, Sedum and grass. Vegetative characters that are found to attribute towards the performance of stormwater runoff are rooting density, structure, density, leaf type, and vegetation biomass.

Keywords: Urban landscape, Urban Hydrology, Water uptake, Native plants, Tropical weather

1. Introduction

Increase in impervious surfaces due to urban development has direct consequences in the increase of stormwater runoff intensity and shorter duration for its occurrence (Yusop et al., 2007). To counter this issue, conventional structural drainage is designed, which is still being used by most cities today to move water runoff quickly out from city centers. Unfortunately, the development of conventional drainage is costly and merely passing water runoff problems of flooding and aquatic pollution to the discharging area (Buccola and Spolek, 2011; VanWoert et al., 2005). Increase in sustainable stormwater runoff management awareness in the recent years has attracted interest in mitigating water runoff through natural landscape approaches. This approach is also known as Best Management Practices (BMP) in various countries (Hathaway et al., 2008). BMP recommends mitigation of stormwater runoff through the development of bio retention areas, wet and dry retention ponds, constructed wetlands, concaved vegetated surfaces and green roofs (Dunnett and Clayden, 2007). Considering the limitation of ground surface in cities for various BMP approach, the only option left is to move stormwater runoff mitigation approaches to the city roof surfaces. This is where green roofs comes in to mimic the natural function of pervious surface.

Green roofs are categorised into intensive and extensive. The difference between intensive and extensive is largely attributed to the differences in substrate depth. Extensive green roofs has a shallower substrate depth than intensive, which is normally 150 mm and below (Metselaar, 2012). In term popularity, extensive green roofs is much more commonly developed due to building weight restrictions and costs (Getter and Rowe, 2009; MacIvor and Lundholm, 2011).

Research shows, extensive green roofs reduces stormwater runoff up to 60-100% depending on green roofs design, substrate depth, slope angle and vegetation species used (Getter et al., 2007; Moran et al., 2005; Van Woert et al., 2005). The formula that have been used to calculate stormwater runoff performance is water runoff = rainfall (water interception + water retention + transpiration from plants + evaporation from soil) (Koehler, 2004). However, this formula does not consider the possibility of surface runoff occurrence, which is a common phenomenon in tropics due to high amount of rainfall.

Green roof's performance in reducing stormwater runoff has been reported by numerous studies. Nonetheless, the role of low growing vegetation in influencing stormwater runoff reduction on extensive green roofs have been greatly overlooked. Most researchers tend to ignore the possibility of improving stormwater runoff performance on green roof through vegetation variation (Lundholm et al., 2010; Wolf and Lundholm, 2008). Reports from Monterusso et al. (2005), VanWoert et al. (2005), Mentens et al. (2006), Getter et al. (2007), Teemusk (20070 and Berndt-

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sson (2010) suggest that vegetation does not significantly contribute towards stormwater runoff reduction, compared to substrate depth and slope angle. Nevertheless, Dunnett et al. (2008) argued that previous research reports tends to use only Sedum species for experiments and ignored the possibility of improving stormwater runoff reduction by using other low growing types of vegetation. Wolf and Lundholm (2008) studied vegetation drought tolerance on green roof suggests, difference in plant growth form and evapotranspiration rate significantly affects water uptake for survival. Difference in water uptake has direct relationship towards differences in stormwater runoff reduction. Therefore significantly affecting the ability for the substrate to absorb and retain more water during a rainfall event. An experiment done by Berghage (2007) showed evapotranspiration rate difference between plants characteristics could be up to 40%.

In the present study, we investigated on how various types of low growing vegetation could potentially influence stormwater runoff amount. Understanding how different types of vegetation react on interception and uptake of water runoff would greatly benefit landscape architects in developing a green roof that are much more effective in reducing stormwater runoff. Tropical countries would benefit much from this study, as stormwater runoff event is a common phenomenon that has been continuously causing mass destruction.

2. Experiment Method

2.1. Site, experiment setup description & data collection

A simulated extensive green roof module was constructed at the third floor of a building in the Faculty of Built Environment, Universiti Teknologi Malaysia. All modules are placed 1 metre from floor level on a platform. The site is open to sky and the experiment platform is placed strategically avoiding any falling shades from surrounding buildings. Sampling types used consist of a fern, herb, grass and succulent (Table 1). Sampling species selection was done based on three criteria. The first criteria is the consideration of vegetation selection based on standard green roof plants requirements, rapid cover spread, low mat forming, succulent leaves and shallow rooting (FLL, 2002; Oberndorfer et al., 2007; Tan, 2008). The second criteria filters sampling selection based on difference in its characters of leaves, height, biomass, and root density. This was done to determine whether difference in vegetation character contribute towards a difference in water runoff. The last criteria was to consider tropical native plants that are found to germinate naturally on local roof surfaces as the preferred plant for experiment. This is because native species have adapted well to local weather and are able to withstand harsh condition (Butler et al., 2012; MacIvor and Lundholm, 2011). Nevertheless, A nonnative Sedum species was also selected. The Sedum species was used as the control species, as it is the most commonly used plant in green roof experiments (Jim and Peng, 2012; Monterusso et al., 2005; Villarreal and Bengtsson, 2005).

Sampling is planted in black PVC trays of 350×270×110 mm deep which simulates an extensive green roof module. The module itself is made up of 100 mm substrate and 10 mm of gravel at the base to substitute the standard drainage layer (Musa et al., 2011; Velazquez, 2005). Each type of sampling modules is replicated three times. All sampling are then established for two month in a green house before it is moved to the weather exposed experiment platforms. Each module is placed on the platform randomly to avoid any data variation due to spot weather condition (Berghage et al., 2009).

Stormwater runoff reduction determinants observed in this experiment are surface water runoff and infiltrated water runoff from the green roofs modules. Evapotranspiration test from the green roof modules was also done to further validate the findings. Stormwater runoff performance calculation is modified and simplified from a previous research by Koehler (2004), where surface runoff is added into calculation. Water runoff = rainfall (Infiltrated water runoff + surface water runoff). While the loss of water due to transpiration is measured through an evapotranspiration test adopted from a previous research done by MacIvor and Lundholm (2011).

Data collection for the stormwater runoff test was done for 62 days from 7 July ~ 6 August 2012, where the site experienced seasonal weather of southwest monsoon. Weather is recorded on site with Davis Vantage Pro 2 Weather station. Parameters that are measured by the weather station are rainfall intensity, wind speed and temperature. A storm event is defined by rainfall period separated by more than 6 hours (Kasmin et al., 2010). For further analysis purposes, all rainfall events was catego-

Table 1. Description of sampling used in the experiment

Species	Family	Origin	Type	Characteristic
Nephrolepis biserrata	Polypodiaceae	Malaysia	Fern	Linear leaves creating pinnate form, fast growing, dense rooting
Cynadon dactylon	Poaceae	Malaysia	Grass	Lanceolate leaves, growing in a spreading twig form
Kaempferia galanga	Zingiberaceae	Malaysia	Herb	Dense, low growing, wide thick leaves, spreading through its bulbs
Sedum mexicanum	Crassulaceae	Mexico	Succulent	Dense rosette of ovate shaped leaf, high tolerances towards periodic drought.

rised by intensity based on recommendation by Malaysia Department of Drainage and Irrigation (DID, 2013). Rainfall intensity of 1~10 mm is categorised into light. Rainfall intensity of 11~30 mm and 31~60 mm is categorised into moderate and heavy. Very heavy category is events with rainfall intensity exceeding 61 mm.

To measure infiltrated runoff, the base of each module is drilled and connected to a water collection tank below via a PVC pipe. The same vegetation type replication is connected to the same water collection tank (Fig. 1). Collected infiltrated water runoff is weighed with CAS 20 LBS Class III digital bench scale after every rainfall event. The weight of the infiltrated runoff are then converted into mm for analysis purposes (Berghage et al., 2009). A standard runoff coefficient from Drainage Criteria Manual (2007) is used to predict potential surface runoff amount. Criteria's that are selected in determining runoff coefficients are Slope surface 0~2%, land use as grass and farmland, and soil type as max clayey. Based on the criteria's selected, the runoff coefficient used to predict surface runoff was 0.25.

Evapotranspiration test is a modification from a similar research by Maclvor and Lundholm (2011). The objective of the test was to identify water loss rate from different types of vegetation. Vegetation with the highest evapotranspiration rate would likely retain more water during a rainfall period. Water loss is determined by weighing green roof modules in an interval of hours with digital bench scale. Difference in weight is considered as water loss due to evapotranspiration. All modules are weighed before the initiation of evapotranspiration test. Approximately 1.4 kg of water was added evenly on each module using a watering can over a period of 45~60 seconds, signifying 20 mm rainfall intensity. The amount determination for the watering is based on daily average rainfall monitoring (DID, 2013). The modules are then weighed for the second time 10 minutes after watering, approximately at 7.00 am. This is done to measure water retained by green roof modules. The modules are then weighed every 12 hours for the next 48 hours. If an event of natural rainfall occurred within the 48 hour of test time, data collected are discarded and the test is repeated again. All modules replication were weight within 1.5 hours to reduce the possible difference of weight over time (Spengen, 2010). To determine the significance of difference in stormawater runoff amount and evapotranspiration from different types of vegetation, one way ANOVA (Minitab release 16) was used.

3. Results

Thirty-one rainfall events resulted in 299.2 mm of rainfall depth. Thirteen events from medium and heavy rainfall intensity had consistently produced water runoff. While light rainfall intensity recorded water runoff twice out of 18 events. Very heavy rainfall intensity was not observed during the experiment period. Extensive green roof in this experiment produced 216.5 mm of combined infiltrated and surface runoff, this result equals to 28% of overall stormwater runoff amount reduction. The major cause for the increase of combined water runoff is due to high amount of infiltrated runoff at 47% of total rainfall (Fig. 2). The performance of stormwater runoff reduction varies significantly depending on rainfall intensity. Water runoff from light and medium rainfall intensity was reduced by 57.8% and 34.6%. Heavy rainfall intensity reduced the least amount of stormwater runoff with only 2.6% (Fig. 3). ANNOVA results for diffrences in amount of water runoff and evapotranspiration from different type of plants showed there are significance diffrence ($p<0.05$).

Two out of 3 native plants had higher stormwater runoff reduction compared to the non native *Sedum mexicanum* species (Fig. 4). *Nephrolepis biserrata* had the best water runoff reduction at 133.4 mm. *Kaempferia galangal* came

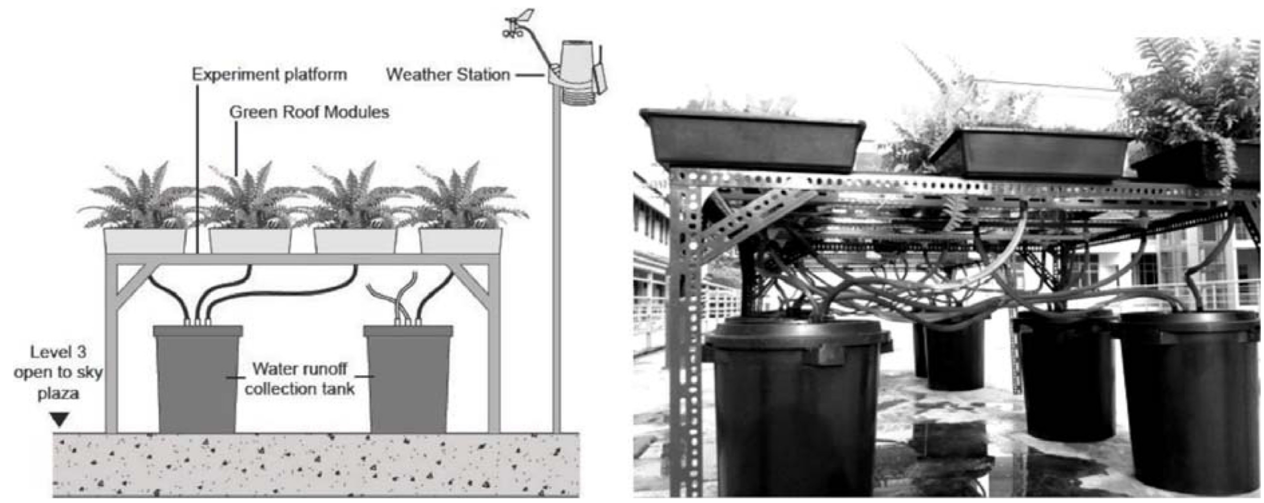

Figure 1. Stormwater runoff measurement experiment setup.

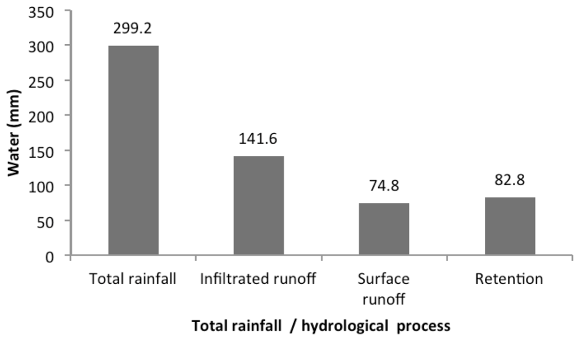

Figure 2. Volume of total rainfall compared to infiltrated runoff, surface runoff and retention by green roofs.

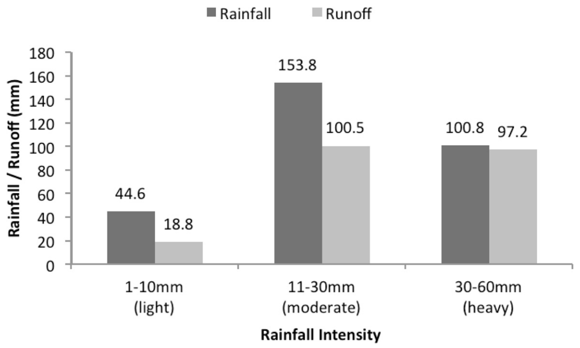

Figure 3. Volume of water runoff as per rainfall intensity.

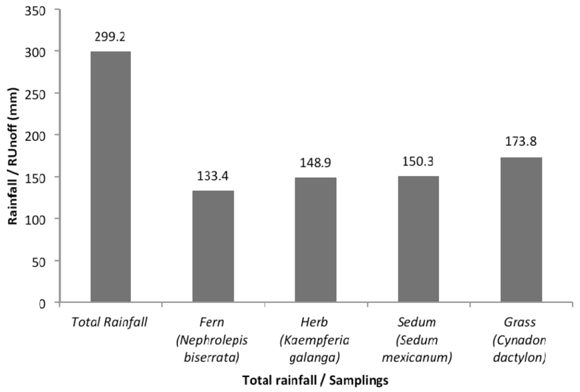

Figure 4. Water runoff from different plant types compared with total rainfall.

in second with 100.5 mm of water runoff, followed closely by *Sedum mexicanum* with a minor difference of 1.4 mm water runoff. *Cynadon dactylon* reduced the least of amount water runoff at 40.4 mm of stormwater runoff, this equals to 13.4% of overall difference from *Nephrolepis biserrata*.

The result of evapotranspiration rate by vegetation was similar to the result of runoff. Water loss was high during the day (7.00 am ~ 7.00 pm). All samplings maintained the water loss ranking by type consistently throughout the 24 hours test (Fig. 5). *Nephrolepis biserrata* had the highest rate of water loss totalling at 0.87 g. This is higher by 0.325 g from the lowest sampling *Cynadon dactylon*. Difference in vegetation type contributes up 61% of difference in evapotranspiration.

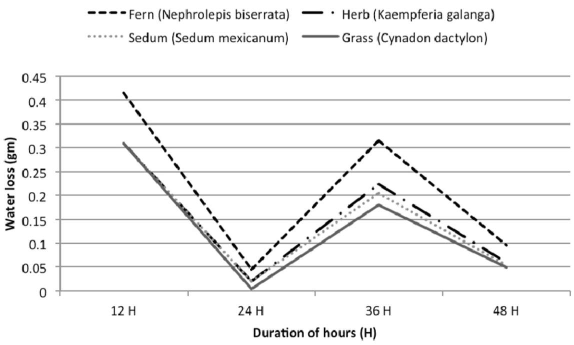

Figure 5. Evapotranspiration from different plant types.

4. Discussion and Conclusion

It was shown that there are differences in water runoff reduction by different vegetation types. The fern samplings were the most effective in reducing water runoff, followed by herbs, sedum and grass. Grass sampling performance was similar to the experiment results of Wolf and Lundholm (2008), where grass had the lowest water runoff reduction. A study by MacIvor and Lundholm (2011) suggest grass type of plants has lowest water runoff reduction capability due to its dense fibrous rooting. However, the findings are not consistent with another research report. Nagase and Dunnett (2012) reported that grass was the best in stormwater runoff reduction, where it outperformed forbs, succulents and sedums due to dense fibrous rooting. To investigate further, we harvested samplings from the modules to observe rooting density. Increase in rooting had significantly decreased substrate porosity, hence effecting water runoff retention.

Increase in vegetation structure density and leaf character had a relationship with reduction of stormwater runoff. This might be the reason behind *Nephrolepis biserrata* and *Kaempferia galanga* species performed better compared to other samplings. Dunnett and Clayden (2007) suggest vegetation structure and leaf intercepts stormwater runoff and slightly reducing water runoff reaching substrate surface. *Nephrolepis biserrata* performance was largely attributed to its dense structure and leaf type. While *Kaempferia galanga* are due to its wide waxy leaf surface, which enables it to hold water in the center of surface creating the lotus effect. *Cynadon dactylon* and *Sedum mexicanum* used in the experiment had very thin leaves, leaving no opportunity to hold stormwater runoff upon interception.

Another character that had direct relationship towards stormwater runoff reduction was vegetation biomass size. Nagase and Dunnett (2012) reported a significant relationship in the increase of vegetation size towards stormwater runoff reduction. A similar finding was identified where *Nephrolepis biserrata* species used in this experiment had significantly larger biomass than other samplings had the best stormwater reduction rate. Even though we did not physically measure the difference in above ground vegetation biomass, the difference was visually obvious. The effect of biomass size is closely related to water uptake and the process of evapotranspiration by plant (Berghage, 2007). Vegetation uptake water from the substrate and store them within its tissues. The water stored are then lost to the atmosphere through evapotranspiration (Getter et al., 2007; Kasmin et al., 2010). Therefore, the increase in vegetation biomass would increase the volume of water involved in the process of uptake and evapotranspiration. This prepares the substrate to able to retain more water during a rainfall event. Findings in evapotranspiration between plants show the difference could be up to 61%, far exceeding the 40% of evapotranspiration difference suggested by (Berghage, 2007). This data shows evapotranspiration activities are high in the tropics compared to the temperate, hence significantly showing a much more effective stormwater runoff performance.

The use of native vegetation in this experiment proved beneficial, as none of the samplings wilted out during experiment period. At the end of the experiment, *Sedum mexicanum* cover rate was in patches compared to the native samplings. It is assumed Sedum species do not thrive well in periodic wet and dry condition of the tropics. The structure of sedum was prone to breakage during medium and heavy intensity rainfall events. There are also reports from North America where the overuse of non-native Sedums led to insect infestation, diseases, mold and fungus (Sutton, 2008). We recommended the use of locally occurring native species compared to the research established sedum species for future research and green roof development. However, this does not mean all native plants are suitable for extensive green roof, there is still a need to consider the standard green roof vegetation criteria's into consideration prior to vegetation selection (Monterusso et al., 2005).

Our findings demonstrate the first evidence of difference in native tropical vegetation characteristics towards stormwater runoff reduction. Different types of vegetation species do affect stormwater runoff amount differently. Therefore, planting selection criteria that consider fast water uptake, high evapotranspiration rate, dense structure, wide leaf area, and large biomass size would greatly enhance stormwater runoff reduction. The substrate also plays an important role in retaining initial rainfall. Despite the large of stormwater runoff compared to the minimal retention performance at 27% of total rainfall, it still translates into large amount of reduction considering the 3000 mm of average rainfall annually in the tropics. Aside from our suggestion on vegetation criteria selection, we recommend the implementation of water harvesting method in significantly reducing stormwater runoff amount. As most of the runoff amount is produced by infiltrated runoff. This would significantly increase stormwater runoff reduction up to 74%.

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