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Evapotranspiration Measurement and Estimation of Crop Coefficient for Native Plant Species of Green Roof in the Tropics

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Citation: Chow, M.F.; Bakar, M.F.A.; Wong, J.K.; Ling, L. Evapotranspiration Measurement and Estimation of Crop Coefficient for Native Plant Species of Green Roof in the Tropics. *Water* **2021**, *13*, 1669. <https://doi.org/10.3390/w13121669>

Academic Editors: Cristina M. Monteiro and Cristina Matos Silva

Received: 7 January 2021

Accepted: 9 June 2021

Published: 15 June 2021

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Abstract: Extensive green roof is one of the sustainable urban stormwater management alternatives to manage and mitigate the urban surface runoff. In order to implement green roofs more effectively, suitable plant species and substrate components for tropical climate must be identified. The aim of this study is to investigate the evapotranspiration (ET) behaviors in extensive green roofs based on different substrate types and local native plant species. Four green roof test beds containing pro-mixing pot and burn soils were each vegetated with *Axonopus Compressus* (grass) and *Portulaca Grandiflora* (sedum). A weather station with soil moisture sensors was installed to measure the weather and soil moisture data. The results showed that the mean ET rates for grass-pot soil, sedum-pot soil, grass-burn soil and sedum-burn soil were 1.32 ± 0.41 mm/day, 2.31 ± 0.72 mm/day, 1.47 ± 0.39 mm/day and 2.31 ± 0.43 mm/day, respectively. It is noted that environmental parameters such as ambient temperature, solar radiation and wind speed showed significantly positive relationship (p value < 0.01) with ET rates of green roofs except relative humidity. The crop coefficients (K_s) for the studied green roof plant species are estimated based on actual and reference evapotranspiration rates. The sedum planted in burn soil showed the highest crop coefficient (0.64), followed by sedum in pot soil (0.62), grass in burn soil (0.39) and grass in pot soils (0.37), respectively. The findings in this study also showed that substrate with better water retention capacity generally improved the K_s values.

Keywords: evapotranspiration; extensive green roof; green infrastructures; sedum; tropical

1. Introduction

As Malaysia shifts to building itself up as a high income and developed nation, its urban growth tier has risen swiftly, especially in the last ten years. The urban growth in Malaysia is estimated to hit 85% by 2030 [1]. Roads and buildings have taken over nature catchments, triggering the increase of urban stormwater runoff and river erosion. Contrarily, evapotranspiration and ground water recharge have lessened [2–6]. These processes have caused the increases of surface runoff volume and flow rate, resulting in the rising frequency of urban flooding [7–9]. While urban development rises, the challenges around managing and controlling stormwater runoff become tougher [10]. In urban areas, rooftops and transportation systems typically make up roughly 80% of impervious surfaces [11]. Since rooftops typically remain unused and access to open areas at ground

level are restricted, the implementation of green roof is a rational option for bringing more vegetation to urban cities [12,13]. According to Mentens et al. [14] and Stovin et al. [15], unused rooftop space makes up roughly half of impervious urban surface areas. Rooftop runoff is a larger threat to water quantity for urban catchments in comparison to rural catchments since the runoff is able to enter the receiving water bodies with ease at a faster rate, due to the direct rooftops' connectivity to drainage systems.

In some developed countries with temperate climates such as the United States, Canada and the European nations, the implementation of green roofs on commercial buildings is widespread. Meanwhile, the extent of green roof studies in Malaysia is limited, despite having great potential in its development [16]. Although analyzing guidelines and findings developed by foreign countries is beneficial, restrictions still exist due to climate differences between tropical and temperate nations, thus preventing the direct implementation of their roof designs, substrate specifications and plants chosen. More specifically, the climate in Malaysia is described as typically having warm conditions during the daytime, with intense but short periods of thunderstorms in evenings. Monsoon season, which occurs from March to May as well as October to December, accounts for a large portion of the country's rainfall. Dry season, emphasized in February also causes extensive periods of drought occurring in multiple urban areas in the country. This shows that Malaysia's climate is incomparable to nations with temperate climates, especially regarding the distribution of rainfall throughout the year.

To implement green roofs effectively in Malaysia, the optimum plant species and substrate components for tropical climates must be determined. Currently, each green roof is usually made up of a singular plant species, selected only based on its ability to withstand shallow substrates and droughts. It has been observed that typical plant species, which are capable to withstand harsh rooftop conditions, are including sempervivums, exotic sedums and others [17–21]. However, the usage of the previously stated species is only able to create green roofs with the minimum nutrient cycling, wildlife and ecological functions [22–24]. New research implies that the usage of native plants will potentially improve the ecological and aesthetic functions of green roofs.

Green roofs in Malaysia face special circumstances due to high intensity of rainfall, temperatures and potential rate of evaporation. Since the success of green roofs is largely reliant on local weather situations, it is inaccurate to expect green roof success using experiences of temperate nations without local adjusting [25]. Green roof studies executed locally are able to identify appropriate native plant species to be used as stormwater mitigation potential for specific areas. By adapting the usage of native plant species in green roofs, they are better customized to fit local environments, need lower watering and maintenance frequency, increase biodiversity and improve aesthetics as compared to non-native species. Although these benefits are also seen in temperate nations, the lack of research regarding moisture content behavior involving native plants and substrate types for green roofs is still an issue in Malaysia. Hence, this study aims to quantify the evapotranspiration performances of extensive green roof with respect to different native plant species and soil characteristics. The specific crop coefficients for both green roof plant species are also investigated in this study.

2. Materials and Methods

2.1. Experimental Setup

The study area is located in the Putrajaya campus of Universiti Tenaga Nasional (UNITEN), Selangor, Malaysia. The daily temperature at the study site ranges from 25 °C to 34 °C. The monthly rainfall pattern is characterized by two periods of rainy season during the Northeast Monsoon (October- to December) and Southwest Monsoon (late May to September). The mean annual rainfall depth at the study area is estimated as 2234.35 mm based on 25 years of rainfall data from 1990 to 2014. UNITEN's College of Engineering building rooftop was used as the experiment site for this green roof study. Six green roof test beds with dimensions of 1.0 m length × 0.5 m width × 0.2 m height

(shown in Figure 1) were set up for the experiment. These test beds were placed at 1 m above rooftop level with a 2% slope. The slope of green roof test beds was set at 2% as Getter et al. [26] and Van Woert et al. [27] reported that extensive green roof performed the greatest stormwater retention at the 2% slope. Each test bed was located on its own custom-made raised steel structure complete with a drainage pipe connected to a runoff harvesting tank. Two different substrates: pot soil and burn soil were investigated in this study for their moisture content behaviours in extensive green roof. The selection of these two substrate types was decided according to the accessibility and prevalence of use as a horticultural substrate in the domestic landscape industry. Using locally accessible substrates is needed for growing chosen native plants for green roofs. The depth of substrate layer was fixed at 130 mm and was placed on the filter fabric and drainage layers. The depth of the substrates was set as 130 mm depth because this is an extensive green roof system in which the typical maximum soil depth is less than 150 mm [28]. Each substrate type was vegetated with selected local native plant species which are *Axonopus compressus* (grass) and *Portulaca Grandiflora* (sedum). The green roof test beds are categorized as pot soil–grass, pot soil–sedum, burn soil–grass, burn soil–sedum, bare pot soil and bare burn soil, respectively. The vegetation was only watered during rainfall events and they were not mowed throughout the experiment period. All surface areas inside the green roof test bed were ensured that 100% covered by the respective plants. For the maintenance of the composition of plant species and consistent results, any unneeded plants, such as weeds found in the test beds, were eliminated weekly until the end of the monitoring period. Additionally, each substrate type was prepared with no vegetation in the test bed to act as a control in this study.

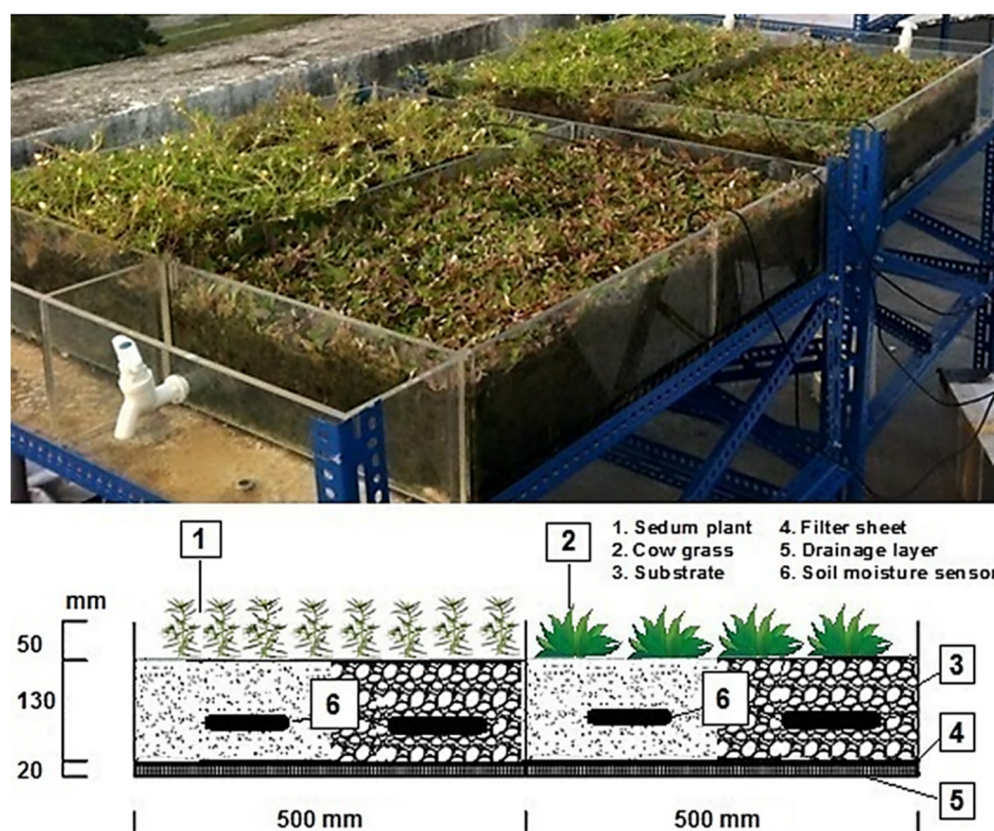


Figure 1. Experimental green roof test beds with sedum & grass plant species.

2.2. Green Roof Vegetation and Substrate Characteristics

A succulent sedum species known as *Portulaca Grandiflora* (as shown in Figure 1) was chosen as one of the green roof plant species in this study. The sedum plant is able to survive in the harsh environment conditions, including strong wind, heavy and intense

rainfall, prolonged dry periods, as well as high temperature and scorching sunshine. The species also exhibits the ability of rapid multiplication, less maintenance, short and soft roots and provides good ground coverage [29]. In this study, the *Portulaca Grandiflora* were obtained from a local nursery in the form of cuttings. The plants were planted in the green roof test beds at a density of 60 plugs/m², covering 100% of the substrate surface. *Axonopus compressus*, which also known as cow grass in Malaysia, was chosen as the second vegetation type in this study. It is a perennial, stoloniferous and short-spreading grass. This species is considered as the native plant in Malaysia and befitting with the local weather and environment. This species has the ability to spread naturally and quickly by stolon and rhizomes under favourable conditions. It is often used as groundcover and turf in moist, particularly in shaded situations, low fertility soils and has permanent pasture. This plant species can grow on a wide range of soils, from sandy to heavy clay loams.

Two locally available soils, known as pot and burn soils, were chosen as the green roof substrates in this study. The elements of pro-mixing potting soil consist of blond peat, perlite, sand, vegetable compost and crushed bricks, while burn soil is mainly made of clay soil burnt over a slow fire for a few days. Both pot and burn soils used in this study were assessed for its characteristics, which including particle size distribution, organic content, permeability, apparent density, total pore volume and maximum water holding capacity. The majority of particle size for pot soil is 425 µm, which accounts for 58.68% of total particle weight. Meanwhile, burn soil is mainly formed by the particle size of 150 µm, which is equivalent to 61.58% of total particle weight. The particle size less than 2 mm contributes 95.22% of total particle weight for pot soil. On the other hand, particle size less than 2 mm in burn soil only contributes 88.74% of total particle weight. The characteristics of both soil types are summarized in Table 1. The pot soil is characterized as high water content, low organic content, high void ratio and high porosity. Inversely, burn soil exhibits higher organic content, higher maximum water holding capability but is lower in both void ratio and porosity. Both soil types have shown significant different in their physical properties.

Table 1. Characteristics of pot and burn soils used in green roof testbeds.

No.	Parameter	Pot Soil	Burn Soil
1.	Organic content, (%)	6.33	29.65
2.	Permeability of soil (k), (mm/s)	0.0008	0.0012
3.	Apparent density of dry soil, (Mg/m ³)	0.095	0.184
4.	Apparent density of full saturation soil, (Mg/m ³)	0.518	0.312
5.	Maximum water holding capacity, (%)	52.60	60.60
6.	Specific gravity (G _s)	1.700	1.230
7.	Dry density of soil (P _d), (Mg/m ³)	0.095	0.184
8.	Void ratio (e)	16.895	5.685
9.	Porosity (n)	0.944	0.850
10.	Water content (w), (%)	14.8	21.9
11.	Degree of saturation (S _r)	0.015	0.047
12.	Air voids content (A _v)	33.54	11.10
13.	Particle density (M _w)	0.251	0.269

2.3. Field Data Monitoring and Collections

A Watchdog 2900ET weather station with data logger was installed at UNITEN's College of Engineering rooftop during the study period. Hourly real-time weather information was recorded by the weather station, which includes wind direction, wind speed, solar radiation, temperature and barometric pressure. All measuring devices were tested and calibrated prior to deployment at the experimental site. The Watchdog weather station is also capable of calculating the evapotranspiration (ET_o) rate automatically based on the on-site weather information. The recorded weather data was downloaded from the experimental site in biweekly basis by using SpecWare Pro software. The maintenance of the weather station was carried out from time to time to check its battery power and func-

tionality of sensor devices. The soil moistness characteristics and behaviour were measured by using Spectrum WaterScout SM100 soil moisture sensors, which placed horizontally in the middle of every test bed. All sensors had been calibrated in the laboratory prior to the installation at the experimental site. The soil moisture content was measured as void water content (VWC) in each green roof configuration in the unit of percentage. Depth-averaged soil moisture content was taken to define the whole soil moisture profile in each green roof test bed. The soil moisture data was recorded at 30 min intervals and stored in the data logger. The FieldScout TDR 100 soil moisture sensor was used to check the soil moisture content of substrate layer from time to time during the study period. The recorded soil moisture data was also downloaded from the experimental site on a biweekly basis by using the SpecWare Spec 9 Pro software.

2.4. Data Analysis

The daily soil moisture content for each green roof test bed was calculated based on the hourly datasets. The daily evapotranspiration (ET_t) rate expressed in millimeter per day (mm/day) for each native plant species in both substrate type was empirically determined in this study. The water balance equation was used to calculate the ET_t value during the monitoring periods as shown in Equation (1).

$$ET_t = P - R - \Delta S \quad (1)$$

Precipitation (P) and runoff (R) are assumed to be zero during the dry periods. The changes of soil moisture content (ΔS) were calculated as the difference of the average daily moisture content over two consecutive days.

The Food and Agriculture Organization (FAO) Penman–Monteith equation as shown in Equation (2) was used to estimate the reference evapotranspiration rate (ET_o) in this study.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (2)$$

where ET_o is the reference evapotranspiration corresponding to well-watered short grass [mm day^{-1}], R_n is the net radiation at the crop surface [$\text{MJ m}^{-2} \text{day}^{-1}$], G is the soil heat flux density [$\text{MJ m}^{-2} \text{day}^{-1}$], T is the mean daily air temperature at 2 m height [$^{\circ}\text{C}$], U_2 is the wind speed at 2 m height [m s^{-1}], e_s is the saturation vapour pressure [kPa], e_a is the actual vapour pressure [kPa], $e_s - e_a$ is the saturation vapour pressure deficit [kPa] and γ is the psychrometric constant [$\text{kPa } ^{\circ}\text{C}^{-1}$].

The evapotranspiration of green roof under standard conditions (ET_t) is computed using a crop coefficient (K_s), which is a crop specific parameter based on the aerodynamic resistance of the plant and the stomatal resistance of the leaf [30,31]. Equation (3) shows the relationship between actual evapotranspiration rate with crop coefficient (K_s) and reference evapotranspiration rate (ET_o).

$$ET_t = K_s \times ET_o \quad (3)$$

where ET_t is the evapotranspiration at a time, t (mm); ET_o is the reference evapotranspiration at a time, t (mm); and K_s is the crop coefficient (dimensionless). The crop coefficient for green roof plant species is calculated according to Equation (4) as below.

$$K_s = \frac{ET_t}{ET_o} \quad (4)$$

In order to investigate the influencing factors for evapotranspiration behavior of green roof, the relationships between daily ET rates and environmental parameters are analyzed in detail. The environmental conditions are quantified through the measurement of ambient air temperature, relative humidity, solar radiation and wind speed. The Spearman rank coefficient was used to determine the relationship between the ET rates and environmental

parameters. All statistical analyses were carried out using IBM SPSS Statistics software version 17.0.

3. Results and Discussion

3.1. Weather and Substrate Moisture Content Profiles during Monitoring Period

The weather and soil moisture content profiles of green roof test beds during the monitoring period were recorded and plotted in Figure 2. The monthly average temperature, relative humidity, solar radiation, wind speed and soil moisture content from November 2015 until October 2016 are plotted as shown in Figure 3. It is observed that the highest monthly mean temperature and relative humidity recorded were 31.4 °C in April 2016 and 82.4% in November 2015, respectively. Meanwhile, the lowest monthly mean temperature and relative humidity recorded were 28.6 °C in November 2015 and 64.6% in February 2016, respectively. Monthly mean temperature has been increasing consistently since November 2015 until April 2016 where it reached the maximum temperature of 31.4 °C. Then, the monthly mean temperatures started decreasing consistently toward the month of October 2016. The maximum values of temperature, relative humidity, solar radiation and wind speed recorded were 31.4 °C in April 2016, 91.0% in November 2015, 507.0 wat/m² in November 2016 and 4.8 km/h in February 2016, respectively. The minimum values of temperature, relative humidity, solar radiation and wind speed recorded were 25.6 °C in June 2016, 44.0% in February 2016, 63.0 wat/m² in December 2015 and 0 km/h in February 2016, respectively. Based on the weather data, it is seen that February, March and April are classified as dry periods with high temperature, low relative humidity and high solar radiation. Based on the rainfall data analysis, a total of 42 dry weather periods showed cumulative dry days greater than two days. The soil moisture behaviours in different green roof configurations were investigated during the monitoring periods. The daily loss of moisture was computed as the difference for daily average moisture content in two consecutive days. Most of the substrate moisture content results showed that green roof planted with sedum species contains higher initial moisture content compared to the green roofs with grass species. In general, green roofs planted with sedum species show higher decreasing rate of substrate moisture content if compared to that of grass species. The daily decrease of substrate moisture content is corresponding well to the temperature and climate conditions [32–34].

3.2. Daily Evapotranspiration (ET) Rates of Green Roof

The primary mechanism used by green roof to replenish their retention capacity in between storm events is through evapotranspiration (ET) process [35–37]. It can thus be predicted that if dry weather period between rainfall events increases, the retention capacity of green roof should increase as the ET process reduces the green roof's substrate moisture content [38–44]. Figure 4 shows the monthly average evapotranspiration (ET) rates for different green roof plant species and substrate types during the monitoring period. The monthly averaged ET rates are 1.32 ± 0.41 mm/day (standard deviation), 2.31 ± 0.72 mm/day, 1.47 ± 0.39 mm/day and 2.31 ± 0.43 mm/day for the grass-pot soil, sedum-pot soil, grass-burn soil and sedum-burn soil, respectively. The highest daily ET rate was recorded as 3.42 mm/day, which was observed for green roof with sedum planted in pot soil in February 2016. Meanwhile, the lowest ET rate of 0.59 mm/day was observed for grass planted in pot soil in March 2016. Generally, lower ET rates are observed in the months of May, June and November as these months are dominated by higher rainfall events, in which total rainfall depths are recorded as 383 mm, 249 mm and 386 mm, respectively.

The ET rates of sedum and grass covers in this study are comparatively lower than that observed by Feng et al. [45] in Salt Lake City (SLC), Utah, USA which has an average annual rainfall of 409 mm and average annual air temperature of 11.5 °C. They reported that the average observed ET rates for the non-vegetated, sedum, and grass covers are 2.01 ± 1.16 , 2.52 ± 1.79 and 2.69 ± 1.69 mm d^{−1} over the one-year study period. The sedum and grass

species that used in their study include sedums (Red Carpet Stonecrop, *Sedum spurium* 'Red Carpet' and Russian Stonecrop, *Sedum kamtschaticum*), and grass (Blue Grama grass, *Bouteloua gracilis*). However, the ET rates of sedum covers in both substrate types in this study are higher than that observed by Rezaei [46] and Marasco et al. [47]. Rezaei [46] found the ET rates of 1.68 mm/d for sedums and 1.06 mm/d for the non-vegetated medium with unlimited water supply in an indoor environment. Marasco et al. [47] also reported the ET rate of 1.71 mm/d for sedums in New York City, USA. Interestingly, this study observed that the ET rates of sedum are slightly higher than the ET rates of 2.27 mm/d reported by DiGiovanni et al. [48] in the Bronx, NY, USA and 2.21 mm/d by Voyde et al. [36] in Auckland, New Zealand. Overall, the hot and humid climate in Malaysia has led to a higher ET rate of sedum plant in green roof compared to other temperate regions.

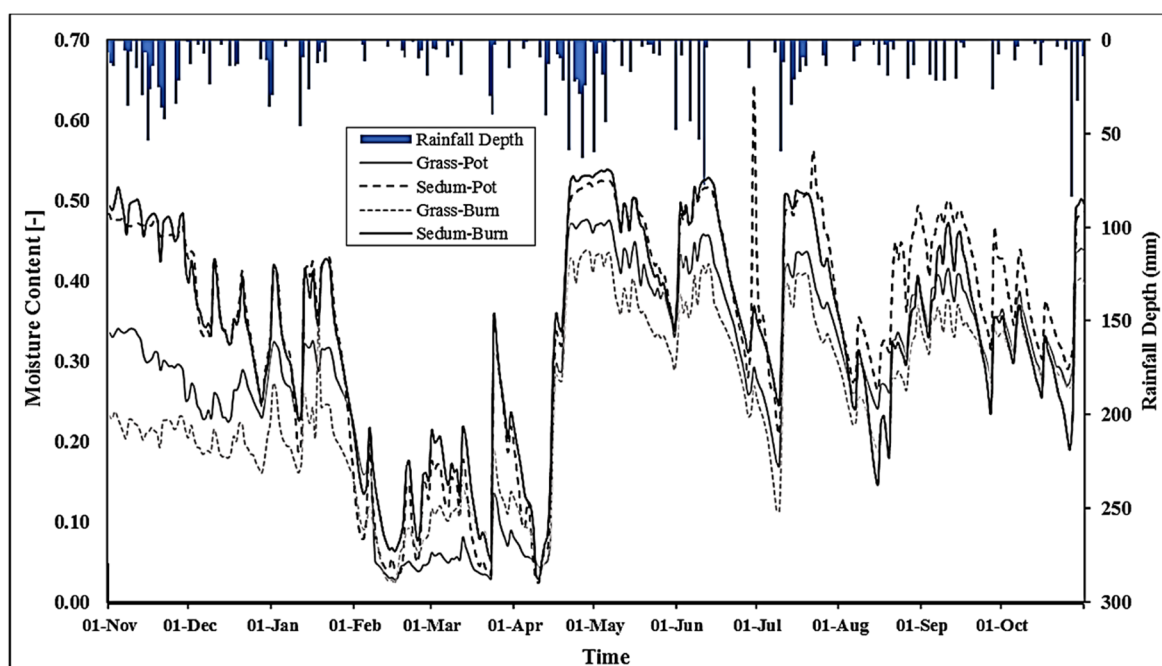


Figure 2. Daily rainfall and substrate moisture profiles at each test bed during the monitoring period from 1 November 2015 to 31 October 2016.

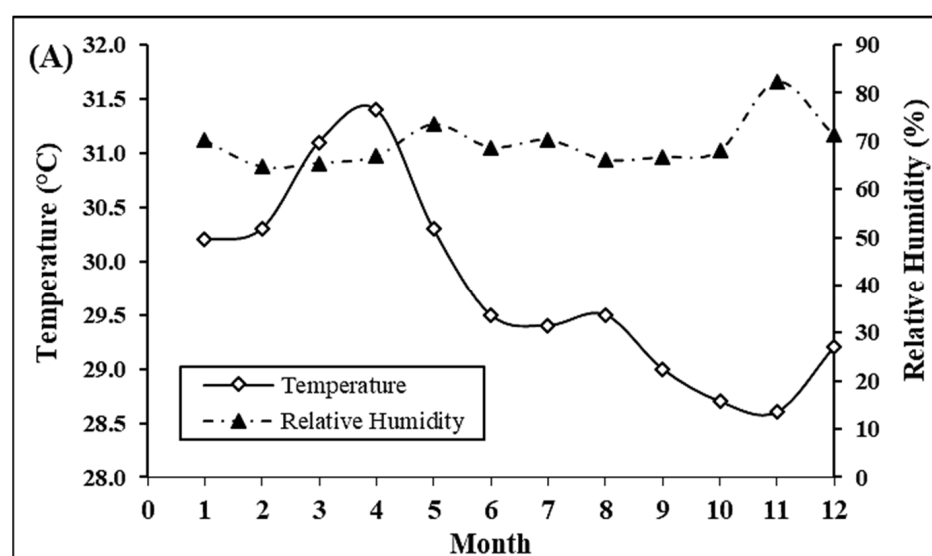


Figure 3. Cont.

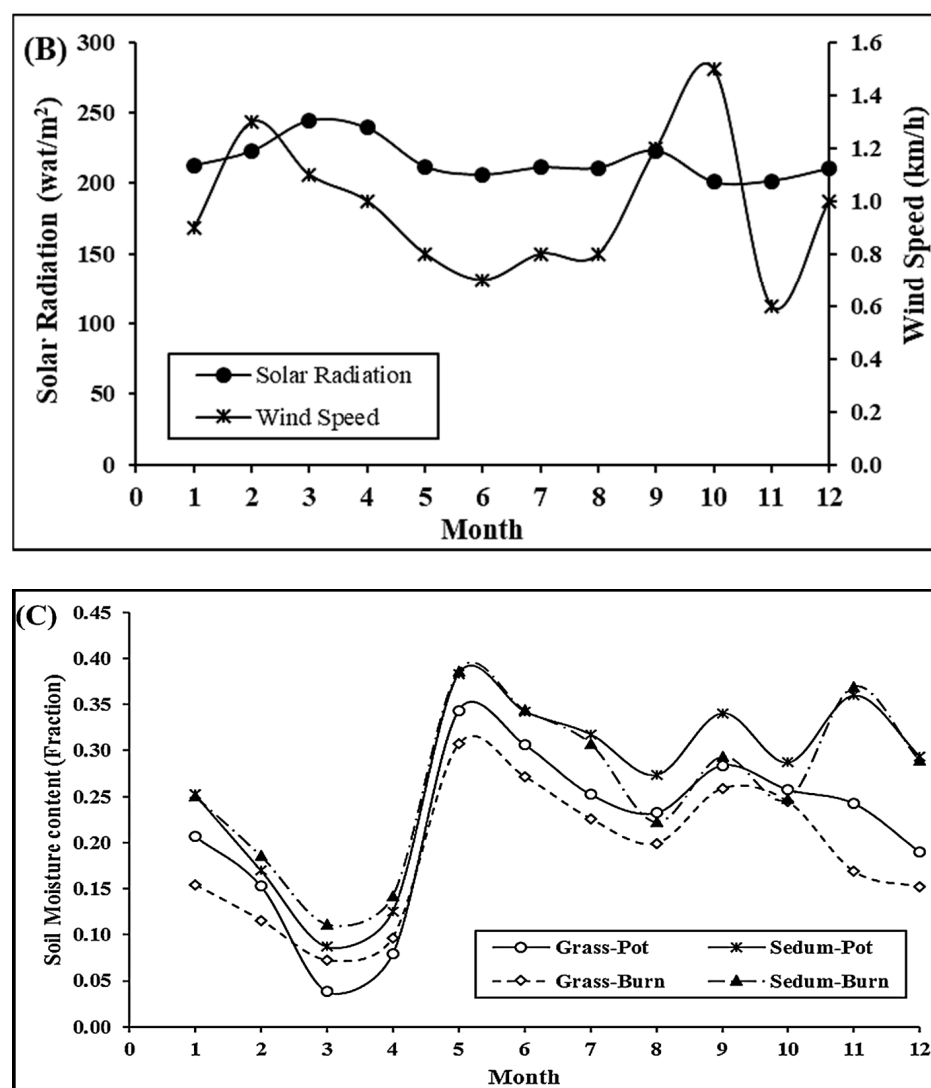


Figure 3. Monthly mean values of (A) temperature and relative humidity, (B) solar radiation and wind speed and (C) soil moisture contents of studied green roofs.

3.3. Relationship between Evapotranspiration Rates and Environmental Parameters

Table 2 shows the correlation results between environmental parameters and ET rates of green roof for each test bed. Generally, it can be noted that most environmental parameters, such as ambient air temperature, solar radiation and wind speed showed a significantly positive relationship (p value < 0.01) with ET rates of green roofs except for relative humidity. These parameters would accelerate the evapotranspiration rates of green roofs. Significant negative correlation was obtained for relative humidity and ET rates of all types of green roofs in this study. This tendency is expected because an increase in relative humidity would lead to a corresponding increase of moisture in the air, thus reduce the evapotranspiration rates of green roof. The increases of temperature and solar radiation are likely to cause greater moisture loss from the extensive green roofs during the dry weather period. Mentens et al. [14] also stated that climatic condition has a great influence on the plant evapotranspiration rate in green roof. Similar finding was reported by Baryla et al. [49] showing that environmental factors such as temperature, solar radiation and wind speed have strong positive influences on the moisture contents of vegetation mat and substrate.

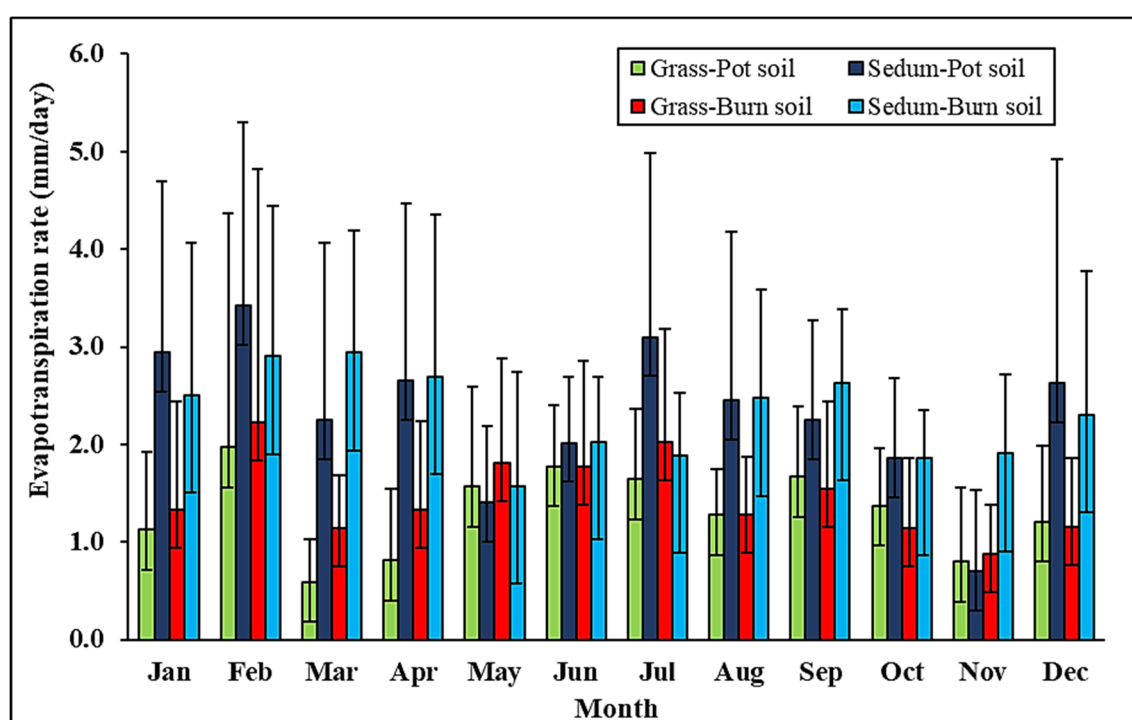


Figure 4. Monthly averaged evapotranspiration (ET) rates for different green roof plant species and substrate types.

Table 2. Correlations between environmental parameters and ET rates of green roofs.

Parameter	Evapotranspiration (ET) Rates			
	Pot Soil		Burn Soil	
	Grass	Sedum	Grass	Sedum
Temperature	0.66 **	0.71 **	0.65 **	0.65 **
Relative humidity	−0.59 **	−0.64 **	−0.54 **	−0.60 **
Solar radiation	0.29 **	0.31 **	0.29 **	0.36 **
Wind speed	0.29 **	0.31 **	0.25 *	0.38 **

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

3.4. Estimation of Crop Coefficient

Differences in leaf anatomy, stomatal characteristics, aerodynamic properties and even albedo cause the crop evapotranspiration to differ from the reference crop evapotranspiration under the same climatic condition [30]. Crop coefficient (K_s) is usually considered specific for the green roof substrates as well as differences between tested types of vegetation with the reference grass crop in the used potential evapotranspiration (PET) model. Ko et al. [50] and Piccinni et al. [51] observed that K_s values may potentially differ between regions. An assumption is made that differing environments among regions allow variations to exist in the selection of variety and stages of development for crops, which affects the K_s value [30]. Therefore, K_s values were determined for every green roof test bed over the monitoring period.

The crop coefficient (K_s) of grass and sedum species varied over time during the monitoring periods are presented as shown in Figure 5. The minimum K_s value of 0.14 was observed for grass in pot soil testbed in March, while the maximum K_s value of 0.96 was observed for sedum in burn soil testbed in December. The average crop coefficients observed in this study are 0.37, 0.39, 0.62 and 0.64 for the grass-pot soil, grass-burn soil, sedum-pot soil and sedum-burn soil, respectively. Notably, the sedum species have higher K_s than grass, which is similar with the findings reported by Wolf and Lundholm [52]. The crop coefficient values of grass species in both substrate types in this study are lower

than that observed by Feng et al. [45], which reported 0.61 for grass species. However, the calculated yearly averages of crop coefficients for sedum species in this study are generally close to that of 0.59 for sedum observed in the study by Feng et al. [45]. The sedum K_s values found by this study are slightly higher than some crop coefficient values reported in some previous studies. Sherrard and Jacobs [53] found the crop coefficient of 0.53 for a well-watered sedum canopy in Durham, New Hampshire, USA. Starry [54] in College Park, Maryland, USA reported an annual average of 0.51 for different sedums while 0.32–0.45 and 0.35–0.52 were observed for sedum species by DiGiovanni [48] and Lazzarin et al. [55], respectively. These green roof studies are mostly conducted in larger areas (range from 600 to 1300 m²) than the green roof area in this study.

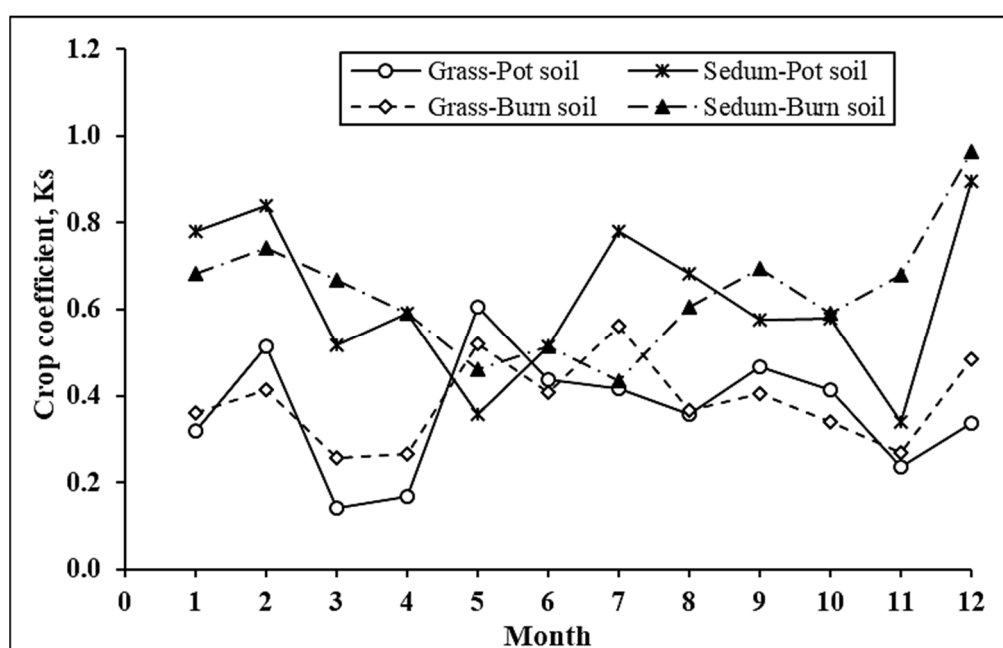


Figure 5. Variation of the crop coefficient (K_s) for different green roofs during the monitoring period.

Interestingly, the K_s values of sedum in this study are generally lower than some findings in previous studies. An average K_s value of 0.85 was reported by Voyde [56] for the well-watered sedum measured using 0.072 m² weighing trays in Auckland, New Zealand; whereas, Schneider [57] observed K_s values range 1.0 to 1.7 for sedums measured with a 0.21 m² weighing lysimeter in Villanova, PA. An average K_s value of 1.35 was observed by Rezaei [46] for sedums from 0.56 m² indoor greenhouse trays. Zanin and Bortolini [58] also found K_s value of sedum as 0.57 for extensive green roofs in a humid subtropical climate. Starry et al. [59] reported the K_s values for three sedum species, ranging from 0.21 to 0.50 for sedum album, from 0.22 to 0.55 for sedum sexangulare and from 0.25 to 0.71 for sedum kamtschaticum, respectively. The results in this study also showed that substrate with better water retention capacity generally improved the K_s values. Cover species planted in burn soil showed higher K_s values than that planted in pot soil in this study. Similar findings were reported by Zanin and Bortolini [58] where substrate with better water retention capacity and drainage/storage layer generally improved the K_s values of green roof plant species.

4. Conclusions

The evapotranspiration (ET) behaviors with respect to different native plants species and substrate types used in extensive green roofs have been investigated in this study. Green roofs vegetated with sedum species show higher evapotranspiration rates compared to that of grass species. Generally, environmental parameters such as air temperature, solar radiation and wind speed showed significantly positive relationship (p value < 0.01)

with ET rates of green roofs, except for relative humidity. The sedum planted in burn soil shows the highest crop coefficient (K_s) for evapotranspiration, followed by sedum planted in pot soil, grass planted in burn and pot soil. These values are within the reported ranges for other studies in rain-rich regions. This study proved that substrate with better water retention capacity would generally improve the K_s value of green roof plant species. The evapotranspiration results have provided more understandings on the hydrological performance of native plant species in extensive green roof in the tropics. The findings from this study can significantly contribute to green roof design in Malaysia.

Author Contributions: M.F.C. and M.F.A.B. conceived and designed the experiments; M.F.A.B. performed the experiments; M.F.C., J.K.W. and M.F.A.B. analyzed the data; M.F.C. wrote the paper; and L.L. and M.F.C. reviewed and proofread the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Malaysia Ministry of Higher Education (MOHE), grant number—FRGS/1/2014/STWN01/UNITEN/02/2 and The APC was funded by BOLD Publication Fund (J510050002) by Universiti Tenaga Nasional.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The authors confirm that the data supporting the findings of this study are available within the article.

Acknowledgments: The authors sincerely thank the Malaysia Ministry of Higher Education (MOHE) for providing the research grant (Vot no: FRGS/1/2014/STWN01/UNITEN/02/2). The authors also thank the BOLD Publication Fund (J510050002) provided by Universiti Tenaga Nasional as well as the support received from Innovation & Research Management Center, Universiti Tenaga Nasional. The authors would also like to thank Samuel C. Zipper for providing valuable comments to improve this article.

Conflicts of Interest: The authors declare no conflict of interest.

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