IOP Conference Series: Earth and Environmental Science

Eco-friendly green roof from biodegradable substrate for stormwater quality improvement

To cite this article: N I Z Mohd Azam *et al* 2024 *IOP Conf. Ser.: Earth Environ. Sci.* **1296** 012003

Eco-friendly green roof from biodegradable substrate for stormwater quality improvement

N I Z Mohd Azam, N S Romali* and A S Abd Razak

Faculty of Civil Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, 26300 Gambang, Kuantan, Pahang.

*Corresponding author's e-mail: suraya@umpsa.edu.my

Abstract. Currently, there is a significant surge of interest in green roof technology for construction buildings due to its numerous environmental benefits, such as stormwater management, energy efficiency, and enhanced urban biodiversity. However, the issue of potential pollutant release from green roof substrates into runoff water, causing water pollution, needs to be addressed. To tackle this concern, a lab-scale green roof model was assessed, utilizing a biodegradable substrate made from banana peels and eggshell waste (organic fertilizer). Three models were tested: a conventional green roof (control), a green roof with chemical fertilizer, and a green roof with organic fertilizer. Various water quality parameters, including pH, total suspended solids (TSS), nitrogen, phosphorus, and potassium (NPK), and chemical oxygen demand (COD), were evaluated. The results demonstrated the effectiveness of organic fertilizer in reducing TSS and COD levels, where the eco-friendly green roof with biodegradable substrate exhibited an impressive performance, achieving a higher COD removal percentage (78%) compared to the green roof with chemical fertilizer (50%). The utilization of organic fertilizer led to an enhancement in the quality of stormwater runoff, resulting in NPK removal percentages ranging from 17% to 25%. Additionally, the organic fertilizer fostered healthier vegetation growth, leading to a greater number of leaves compared to the chemical fertilizer. These findings highlight the potential of eco-friendly green roofs as a sustainable and effective tool for stormwater management, provided suitable substrate materials are employed.

1. Introduction

In recent years, there has been a surge in interest and concern over environmental sustainability and the impact of human activities on the planet. As a result, the adoption of eco-friendly practices has become a pivotal focus for researchers, urban planners, and architects alike. Among these sustainable initiatives, green roofs have emerged as a promising solution to mitigate the adverse effects of urbanization on both water quality and the overall environment. Economical roofs, living roofs, and vegetated roofs are the terms used to describe green roofs. Green roofs are roofing structures that support the growing medium and vegetation by using a system of constructed layers [1, 2, 3]. The growing medium and vegetation are placed on the top of the roofing structure with a stormwater drainage system. Through the combination of five layers in the green roofs system which are vegetation, substrate, filter layer, drainage layer, and the roof membrane, these green roofs offer an effective and sustainable approach to address the challenges posed by urban stormwater runoff and the degradation of water bodies [4, 5, 6]. Generally, the implementation of green roofs is an effective method in the aspect of runoff control by slowing down as well as reducing the composition of rain that is transformed into surface runoff which mitigates

flooding in urban areas [7]. Green roof technology is not only efficient in solving the problems associated with urban food supply while improving the quality of stormwater, but it also promotes economic, aesthetic, and environmental benefits [7].
While green roofs offer numerous benefits for runoff water quality, certain potential negative effects must be considered. Green roof substrates, particularly those with organic components, can leach pollutants like nitrogen, phosphorus, and organic compounds into the runoff water. The use of fertilizers, especially synthetic fertilizers, causes large amounts of nutrient concentrations in the water runoff compared to the control-release fertilizers [8]. So, it is a must to focus on the growing medium layer to improve the runoff quality performance from the green roofs particularly the type of fertilizers used. Without proper maintenance, green roofs may accumulate pollutants like heavy metals, dust, and debris, leading to runoff water pollution during rainfall events. Additionally, stagnant water on green roofs can create a conducive environment for bacterial growth, potentially causing contamination if the water is not adequately drained or if there are design issues. In extreme rainfall events, green roofs may become overloaded, resulting in excess runoff-carrying pollutants into the stormwater system. The amount of pollutants in the water runoff can be influenced by the usage of organic matter in the growing medium, the composition of material and ratio as well as the presence of the microorganism in the growing medium layer of green roofs. It's important to note that many of these negative effects can be mitigated or minimized through proper design, installation, and maintenance of green roofs. Choosing appropriate substrates, managing vegetation, and implementing effective drainage systems can address some of these concerns. Green roofs remain a valuable tool for stormwater management, but it's essential to consider site-specific factors and implement best practices to maximize their benefits and minimize potential drawbacks.
Hence, the primary objective of this paper is to present an in-depth analysis of the composition and performance of an eco-friendly green roof using biodegradable substrate materials. The aim is to highlight the efficacy of the innovative green roof system in improving stormwater quality. Furthermore, employing biodegradable and recycled waste materials as integral components of green roofs presents the substantial potential for nurturing a more environmentally friendly and sustainable future for both urban centers and the global community. This pioneering strategy encompasses a myriad of advantages that actively contribute to the preservation of the environment, the enhancement of urban ecosystems, and an elevated standard of living. Moreover, this study seeks to contribute to the growing body of knowledge on sustainable urban development, offering practical insights for urban planners, architects, and policymakers seeking environmentally responsible solutions to combat the adverse effects of urbanization on water resources. Ultimately, by examining the potential of eco-friendly green roofs, we hope to pave the way for a greener, more sustainable future for our cities and the world.

2. Methodology

The methodology to investigate the performance of green roofs in this study includes the design of a lab-scale green roof system, the production of banana peels and eggshells for green roof substrates, and the examination of enhancements in stormwater quality and plant growth.

2.1. Experimental set-up

A prototype model of the green roof system with a size of 30 cm x 30 cm x 25 cm was built as shown in Figure 1. There are five major layers in the prototype model which are the vegetation layer, growing medium layer, filter layer, and drainage layer. The final layer comprised a waterproof membrane, which was installed by laying waterproof rolls over the platform's base. In Table 1, there are three types of prototypes: G1, G2, and G3. G1 represents the control, which is a conventional green roof. On the other hand, G2 and G3 are two prototypes constructed using different types of fertilizer in the substrate layer. G2 is constructed using chemical fertilizer, while G3 is constructed using organic fertilizer.
To construct the G1, a bituminous flexible membrane (waterproof tape) was laid which acts as a roof membrane. Next, the pebbles were added to the bituminous flexible membrane as the drainage layer and the thickness of this drainage layer is about 4 cm. A kenaf fiber was bonded to the upper surface of the drainage pebbles to prevent the small particles and debris from rainwater or growing media that percolates through the green roof system. It prevents these particles from clogging the drainage system

or reaching the growing medium and root zone. After laying the kenaf fiber as a filter layer of the green roof system, the growing medium was filled for 10 cm thickness on top of the kenaf fiber to provide all the nutrients that are needed for vegetation growth.

Table 1. Green roofs experimental models

Models	Description
G1 (Control)	Conventional green roof
G2	Green roof with chemical fertilizer
G3	Green roof with organic fertilizer

For G2, which involved the use of chemical fertilizer, a specific NPK fertilizer with a 16:16:16 ratio was incorporated into the growing medium layer. The composition in this layer was maintained at a 1:1 ratio, meaning that it consisted of 50% growing medium and 50% fertilizer. The depth of the growing medium is 10 cm. While for the G3, organic fertilizer made of banana peels and eggshell powder was used since it gives an eco-friendly effect to the green roof system because these banana peels and eggshells are from recycled waste materials. The banana peels and eggshell powder were added to the growing medium as a fertilizer and the ratio used was also 1:1. The ratio selection was determined based on a study by Chow and Ahmad Azlan [9], which revealed that the optimal soil-to-bio-compost composition in Malaysian tropical climate conditions is 1:1.

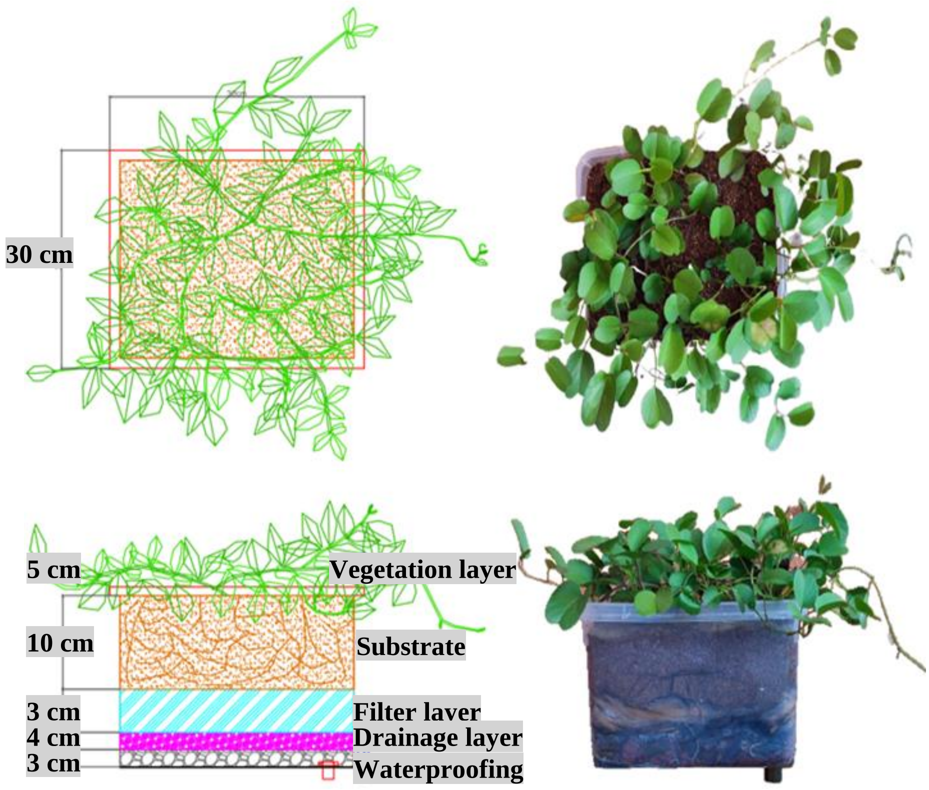

Figure 1. Plan and side view of the green roof model

The type of vegetation used for all prototype models was morning glory (*Ipomoea pes-caprae*). The morning glory is collected at Teluk Chempedak Beach, Kuantan, Pahang. It was planted on the growing medium and after a week of planting, the beach morning glory showed a sign of stress because of the dryness during the first week. However, this type of vegetation will return to its normal condition and adapt to its new surrounding after enough watering [10]. The experiment was carried out at the Hydraulics and Hydrology Laboratory of the Faculty of Civil Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA). The model was placed in an open space to experience a real rainfall event. The stormwater samples are collected at the issue of the outflow of the green roof model.

2.2. Tested parameters

2.2.1. Water quality. The stormwater runoff sample from the green roof prototypes was tested and analyzed at the Environmental Laboratory, Faculty of Civil Engineering Technology, UMPSA to determine the quality of the stormwater runoff. The tested water quality parameters were TSS, COD, pH value, and NPK. The percentage of removal for the TSS and COD was calculated using equation (1) to compare the effectiveness of the green roof between two different types of fertilizer applied.

$$\text{Removal (\%)} = \frac{(Concentration\ of G1)-(Concentration\ of\ G2\ or\ G3)}{(Concentration\ of\ G1)} \quad (1)$$

2.2.2. Plant growth. The vegetation growth is investigated by determining the number of leaves. Measuring the number of leaves is one of the effective methods to evaluate plant growth [11]. Over a span of five weeks, the plants underwent regular observations, and the count of leaves was recorded at each observation instance.

2.3. The production of organic fertilizer using banana peels and eggshell waste

Figure 2 illustrates the sequential steps involved in the creation of the organic fertilizer. The process begins by thoroughly washing the banana peels and eggshell waste with lukewarm water, ensuring the removal of dust, undesired particles, and dirt. Subsequently, the banana peels are chopped into small fragments measuring approximately 1-4 cm, while the eggshells are subject to a precautionary treatment of boiling water for 3-7 minutes to eliminate potential contaminants. Following this, both the banana peels and eggshells are meticulously placed under direct sunlight for a minimum of 7 days, receiving no less than 5 hours of peak sunlight exposure daily. This meticulous drying process ensures the complete elimination of moisture, rendering the banana peels and eggshells thoroughly dry. Once this state of dryness is achieved, the waste materials are finely ground into a powder-like consistency using a grinder. After the grinding phase, the resulting fine powder is blended with the growing medium, forming a cohesive organic fertilizer blend. The organic fertilizer-to-growing medium ratio is carefully maintained at 1:1, ensuring a balanced amalgamation. This meticulous process yields a nutrient-rich organic fertilizer, poised to enrich the growing medium and facilitate optimal plant growth.

Figure 2. The preparation process of banana peels and eggshell powder.

3. Results and discussions

3.1. Water quality improvement

Figure 3 demonstrates the effectiveness of the organic fertilizer in improving the quality of stormwater runoff. The green roof model with organic fertilizer has the lowest total suspended solid (TSS) which is 11mg/L, followed by the green roof with chemical fertilizer (18mg/L) while the conventional green roof results in the highest TSS with 21 mg/L. This finding highlighted that organic fertilizers tend to offer more sustainable and environmentally friendly benefits, as they are less likely to contribute to excessive nutrient runoff and sediment loading, resulting in higher percentages of removal (48%) compared to chemical fertilizers (14%). The TSS concentration in the green roof with chemical fertilizer is higher compared to the one with organic fertilizer because vegetation growth influences the soil release in the runoff. Organic fertilizers can improve soil structure and water retention capacity, reducing soil erosion and the transport of sediment in stormwater runoff.

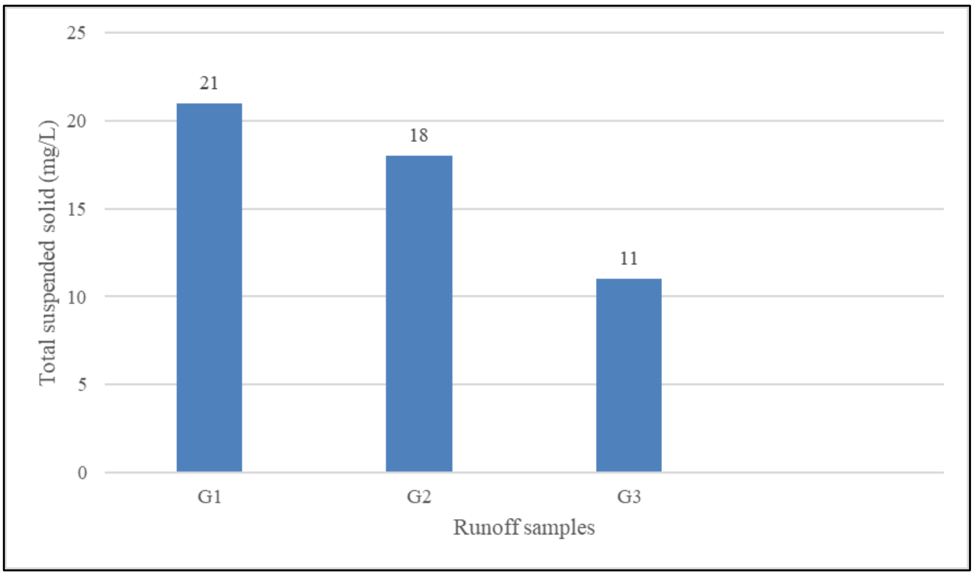

Figure 3. Total suspended solid (TSS) in runoff samples.

The performance of COD concentration is compared between the first flush and after the rapid flush. The first flush is the initial, short-lived phase with highly concentrated pollutants, while the rapid flush represents the ongoing, but usually lower-concentration runoff that continues throughout the rainfall event. During the first flush, the runoff water often carries the most concentrated pollutants and contaminants that have accumulated on surfaces since the previous rainfall. These pollutants can include dust, debris, oils, chemicals, and other substances. Meanwhile, during the rapid flush, the runoff water may still contain pollutants, but the concentration is generally lower compared to the first flush. It includes a mix of rainwater and surface runoff from various areas. As can be observed in Figure 4, the green roof with organic fertilizer resulted in a higher reduction of COD concentration from 87 mg/L to 19 mg /L while the COD concentration for the green roof with chemical fertilizer decreased from 104 mg/L to 52 mg/L and for the conventional roof from 7 mg/ L to 4 mg/L. After rapid flushing, the COD runoff from the green roof is getting lower as the natural nutrient from the substrate have been rinsed off and the vegetation has uptake the nutrient resulting in better growth performance than before. Among the three samples, the green roof with organic fertilizer shows a higher percentage of removal which is 78%, followed by the green roof with chemical fertilizer at 50%, and the conventional roof (control) at 43%.

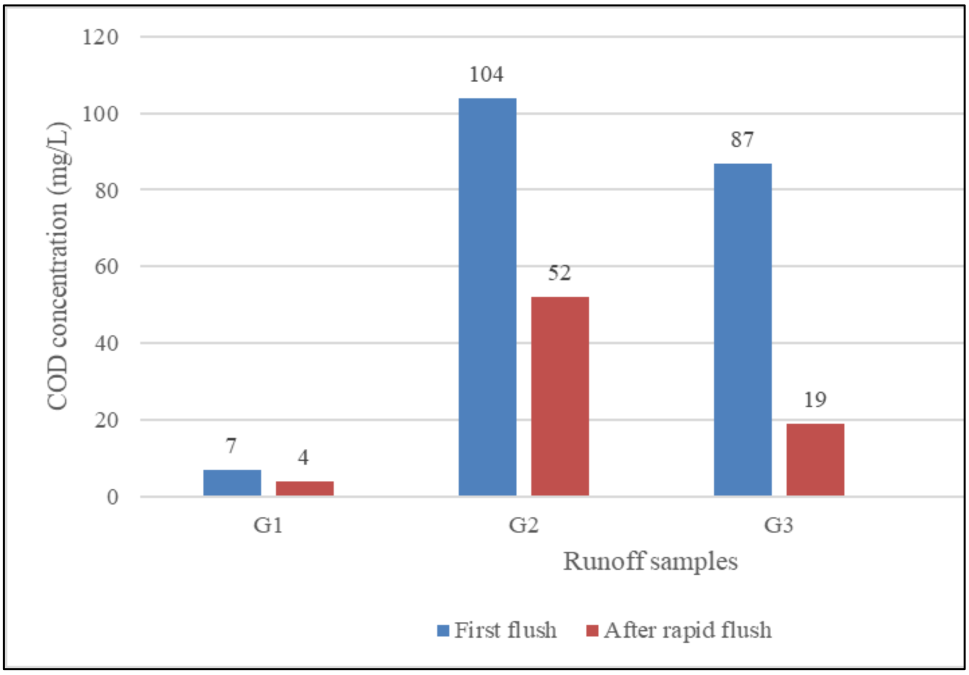

Figure 4. COD concentration in runoff samples

The findings presented in Figure 5 offer a comprehensive insight into the pH variations observed among different runoff samples collected from distinct green roof models and conventional roofs. Notably, the runoff samples from green roof models utilizing chemical fertilizer displayed a notably elevated pH value of 8.45, contrasting with the lowest pH measurement of 6.72 recorded for the conventional roof runoff. In contrast, the runoff sample derived from the green roof model incorporating organic fertilizer demonstrated a pH value of 7.01, positioning it closest to the neutral point on the pH scale. This intriguing observation underscores the potential of organic fertilizer to effectively manage runoff pH. By utilizing organic fertilizer as a growth medium, a green roof can mitigate pH imbalances, contributing to a more balanced and environmentally favorable runoff composition. The influence of green roofs on runoff quality extends beyond pH management; these systems often facilitate the elevation of rainwater pH from a mildly acidic range (pH 5-6) to a more neutral to slightly alkaline range (pH 7-8) in many cases, demonstrating their capacity to positively impact the chemical makeup of green roof runoff water [12]. It is important to recognize that the pH scale spans from the extreme of acidity (pH 1) to the extreme of alkalinity (pH 14). Within natural water bodies, such as streams, the pH typically hovers within the neutral to slightly basic range, commonly falling between 6.5 and 8.5. This pH range is conducive to the well-being of aquatic ecosystems. However, deviations from this range can have detrimental effects. A drop in streamwater pH below 5.5 can threaten fish survival due to excessive acidity, while a rise beyond 8.6 may lead to water becoming excessively alkaline, potentially disrupting aquatic habitats [9].

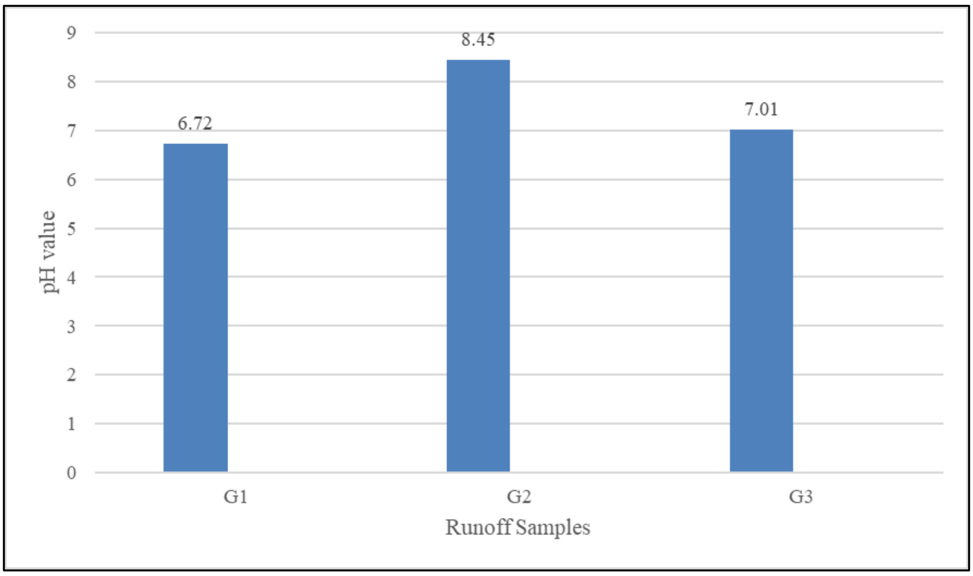

Figure 5. pH values in runoff samples

The percentage of NPK removal is used to assess which model effectively retains more NPK in the substrate for vegetation growth rather than allowing it to be released in the runoff. A low percentage of removal indicates that the green roof model releases only a small amount of NPK into the runoff, while the majority is retained in the substrate, which is a desirable outcome for effective nutrient management. The percentage removal rates for organic fertilizer are as follows: N: 25%, P: 17%, K: 24%, which are substantially lower than those for chemical fertilizer: N: 81%, P: 63%, K: 82%, as illustrated in Figure 6. The investigation revealed that the use of organic fertilizer as the substrate layer in a green roof led to significantly lower NPK levels in runoff water compared to the use of chemical fertilizer. Organic fertilizer, known for its slow-release properties, gradually provides a consistent quantity of nutrients to the vegetation over time. Consequently, it contributes to reducing the concentrations of nitrogen (N), phosphorus (P), and potassium (K) in runoff. This finding suggests that organic fertilizer outperforms chemical fertilizer in terms of water quality performance for green roofs.

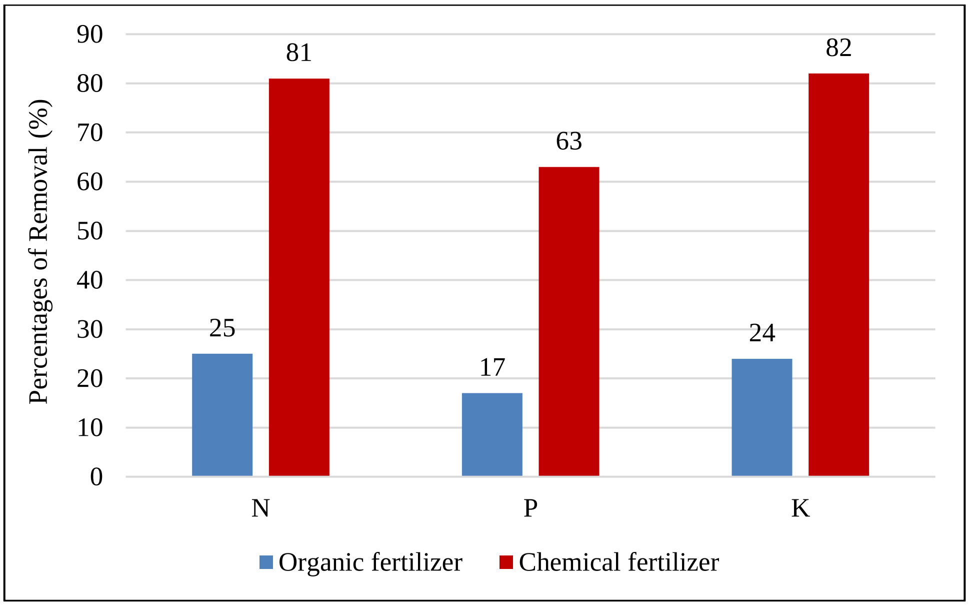

Figure 6. Percentages of removal for NPK

IOP Conf. Series: Earth and Environmental Science 1296 (2024) 012003 doi:10.1088/1755-1315/1296/1/012003

3.2. Plant growth

The organic fertilizer produced the highest number of leaves. It was discovered that banana peels and eggshell powder had a substantial impact on the numbers of the leaves where they provided sufficient nutrients for vegetative growth. As a result, beach morning glory with organic fertilizer is healthier and has the highest number of leaves. Figure 7 illustrates the progression of plant growth, as measured by the number of leaves when comparing the effects of organic and chemical fertilizers over a five-week period. In the initial week (Week 1), plants treated with organic fertilizer exhibited a slightly higher leaf count of 39, in contrast to those treated with chemical fertilizer which had 35 leaves. As the observation progressed to Week 2, both experienced an increase in leaf development, with the organic fertilizer-treated plants reaching 59 leaves and the chemical fertilizer-treated plants slightly behind at 58 leaves.

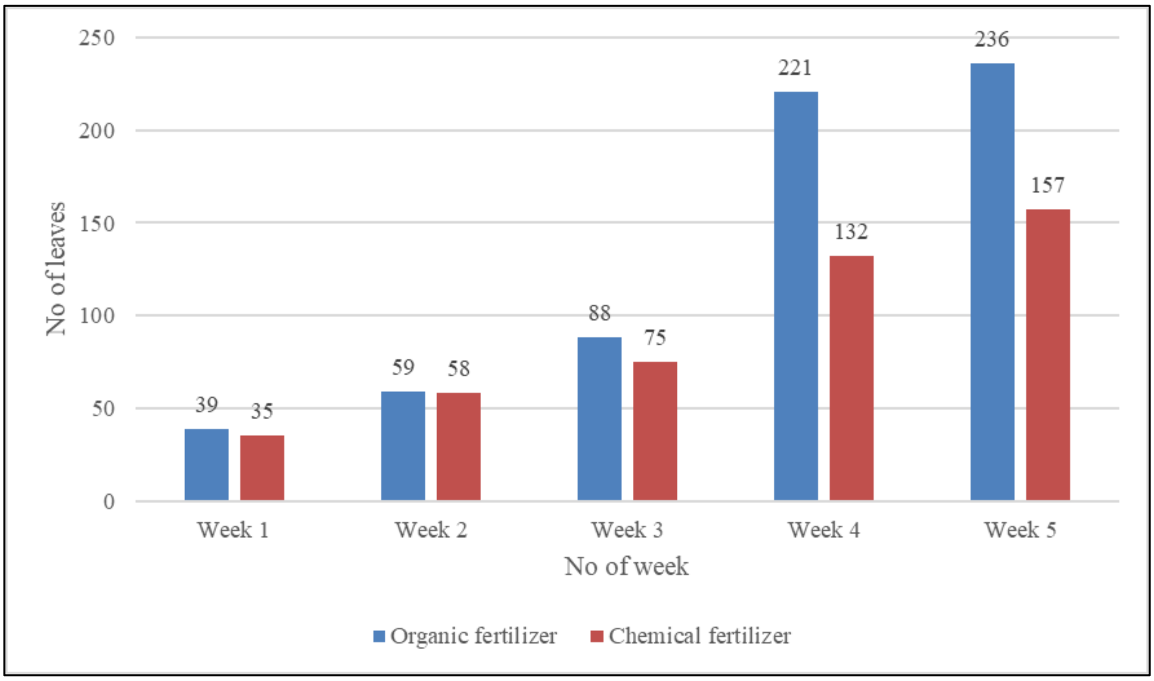

Figure 7. Vegetation growth in different types of fertilizer

Notably, the divergence between the two fertilizers became more pronounced in Week 3. The plants treated with organic fertilizer displayed robust growth, evidenced by a leaf count of 88, while the plants treated with chemical fertilizer had 75 leaves. This trend continued into Week 4, when the organic fertilizer group experienced a substantial surge in leaf production, reaching 221 leaves. In contrast, the chemical fertilizer-treated plants showed a more modest increase, with a leaf count of 132. By Week 5, the impact of the different fertilizers on plant growth was even more apparent. The organic fertilizer group continued to flourish, boasting a leaf count of 236, while the chemical fertilizer-treated plants lagged at 157 leaves.

The results suggest that the application of organic fertilizer consistently promoted more vigorous and accelerated plant growth, as evidenced by the consistently higher leaf counts throughout the five-week period. On the other hand, while the plants treated with chemical fertilizer also exhibited growth, the growth rate appeared comparatively slower. These findings underscore the potential advantages of using organic fertilizers in fostering more robust and prolific plant development, which could have implications for various agricultural and horticultural applications.

4. Conclusion

The green roof prototype model has been constructed in this study using biodegradable waste materials from banana peels and eggshells to improve the quality of the urban stormwater and help in vegetation growth. The significance of this study is to evaluate the ability to use recycled waste materials as fertilizer in the substrate layer of the green roof. In conclusion, this study has illuminated the significant potential of an eco-friendly green roof system utilizing a biodegradable substrate for the enhancement of water quality in urban environments. The results underscore the multifaceted benefits of this innovative approach, revealing substantial improvements across a spectrum of water quality parameters. The investigation into pollutant removal efficiency yielded compelling insights. The green roof incorporating organic fertilizer emerged as a standout performer, showcasing an impressive 78% reduction in Chemical Oxygen Demand (COD). This was followed by the green roof with chemical fertilizer, achieving a commendable 50% reduction, and the conventional roof (control) exhibiting a notable 43% reduction. Furthermore, Total Suspended Solids (TSS) reductions were particularly pronounced in the organic fertilizer-treated green roof, with a significant 48% removal, while the chemical fertilizer exhibited a more modest 14% reduction. Regarding pH levels, the green roof models demonstrated a distinct influence on runoff pH. The models utilizing organic fertilizer achieved a pH value of 7.01, approaching neutrality, while the chemical fertilizer-treated green roof exhibited a higher pH of 8.45. This variation highlights the ability of organic fertilizer to contribute to pH regulation, thereby potentially mitigating the adverse effects of pH imbalances in runoff water.

The study also unveiled intriguing insights into nutrient management. Organic fertilizers, notably rich in nutrients, exhibited significant reductions in nutrient content, with NPK parameters showing reductions of 17% to 25%. Similarly, chemical fertilizers contributed to substantial nutrient reductions, particularly in nitrogen by 93%. These findings suggest that the utilization of organic fertilizers can effectively modulate nutrient levels, with implications for soil health and optimal plant growth.

Plant growth assessment, measured through leaf count, indicated a clear advantage for the application of organic fertilizer. Throughout the five-week observation period, organic fertilizer consistently promoted more robust and accelerated plant growth, as evidenced by higher leaf counts. In contrast, chemical fertilizer-treated plants demonstrated growth but at a comparatively slower rate.

In essence, this research emphasizes the potential of biodegradable substrate-based green roofs as an eco-friendly strategy for enhancing water quality and promoting sustainable urban development. The outcomes contribute to the broader discourse on innovative approaches to urban environmental management, advocating for the integration of nature-inspired solutions to address pressing ecological challenges. As urban areas continue to evolve, the findings of this study offer valuable insights into the role of green infrastructure in fostering harmonious and resilient urban ecosystems.

5. References

[1] Chow M F and Abu Bakar M F 2016 A review on the development and challenges of green roof systems in Malaysia *International Journal of Architectural and Environmental Engineering* **Vol: 10, No:1**, 2016.

[2] Romali N S, Suzany M N and Shahid K A 2023 Green roof for stormwater runoff control: A review *AIP Conference Proceedings* **2688, 040001** (2023).

[3] Ismail W Z W, Abdullah M N, Hashim H and Rani W S W 2018 An overview of green roof development in Malaysia and a way forward *AIP Conference Proceedings* doi: 10.1063/1.5055460

[4] Cascone S 2019 Green roof design: State of the art on technology and materials *Sustainability* **11, 3020**.

[5] Romali N S, Othman N S and Mhd Ramli N N The application of green roof for stormwater quantity and quality improvement *IOP Conference Series: Earth and Environmental Science* **682** (2021) 012029.

[6] Romali N S, Ardzu F A and Suzany M N 2023 The potential of coconut waste as green roof materials to improve stormwater runoff *Water Science & Technology* **87(6) 1515** DOI: 10.2166/wst.2023.060

[7] Liu W, Wei W, Chen W, Deo R C, Si J, Xi H, Li B and Feng Q 2019 The impacts of substrate and vegetation on stormwater runoff quality from extensive green roofs *Journal of Hydrology* **576** (2019) pp 575-585.
[8] Vijayaraghavan K 2016 Green roofs: A critical review on the role of components, benefits, limitation and trends *Renewable and Sustainable Energy Reviews* **57**, pp. 740-752
[9] Chow M F and Ahmad Azlan A A 2020 Assessing the performance of bio compost as soil media in extensive green roof *IOP Conference Series: Materials Science and Engineering* **713 (2020) 012012.**
[10] Shahid K A, Syed Mohsin S M and Ghazali N 2016 The potential of cooling effect using palm oil clinker as drainage layer in green roof system *ARPN Journal of Engineering and Applied Sciences* **Vol. 11** No. 11 2016.
[11] Farjon G, Itzhaky Y, Khoroshevsky F and Bar-Hillel A 2021 Leaf counting: Fusing network components for improved accuracy *Front. Plant Sci.* **12:575751**.
[12] Wang H, Qin J, and Hu Y (2017) Are green roofs a source or sink of runoff pollutants? *Ecological Engineering* **107(3888),** pp. 65-70

Acknowledgments
The authors are grateful to Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA) for the financial support through UMPSA Fundamental Research Grant RDU210323. Besides, technical support and encouragement from the laboratory staff of the Faculty of Civil Engineering Technology, UMPSA are appreciated.