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The effects of different materials of green roofing on the quantity and quality of stored and drainage water by using simulated rainfall setup

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ABSTRACT

One of the methods to control the rain on the spot and reuse it is the green roof. This method uses a multi-layer system of vegetation on the roof and balcony of a building to absorb part of the rainwater; the volume and peak runoff are also reduced by evaporation, transpiration, and treatment processes. This research was conducted as a field experiment in the hydraulic laboratory of the Agriculture Faculty in the University of Zanjan, Iran. The factors of the study design included a green roof covered with shards of brick and cultivated soil (grass). The experiments were performed at rainfall intensities of 45, 55, and 65 mm/h with 5, 10, and 25 year return periods, respectively. Also, the volume of the water stored and drainage was measured in different conditions. The results of this study showed that regardless of the type of materials used in the green roof, with increasing time, the amount of water stored in the green roof decreased, and the amount of drained water increased. A comparison of the average performance of the brick and grass modifiers for green roofs showed that the volume of the stored water in the grass corrector was higher; if the shards of bricks were used, 69% of the rainfall would be stored, and 31% was drained. However, adding grass to the green roof increased the volume of stored water to 78% and reduced the volume of drainage water to 22%. Also, the presence of grass on the green roof reduced the electrical conductivity by 32% compared to the single brick.

1. Introduction

The United Nations released a report in 2011 showing that more than half of the world's population lives in urban areas. And over the next four decades, the world's largest population growth will occur in urban areas. Such an increase will lead to larger urban areas, which will increase impenetrable areas and cause many environmental

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problems [1-3]. Today, many important cities worldwide have paid more attention to the concept of sustainable development to reduce the negative effects of their city development on the quality and quantity of runoff by using modern management technologies, including Best Management Practices (BMP) and Low Impact Development (LID). These methods promote a better balance among natural resource conservation, growth and development, ecosystem protection, public health, and quality of life [4-8]. One of the methods to control the rain on the spot and reuse it is called the green roof method. It is a multi-layer system that covers the roof and balcony of a building with vegetation to absorb and preserve a part of the rain; the evapotranspiration and treatment processes reduce the volume and peak of the runoff and the dimensions of the downstream drainage system, which improves the quality of weather, preserves the beauty of cities, and prevents energy loss of the buildings [9-15]. The effectiveness of green roofs in reducing the runoff volume and peak will be higher in areas where the percentage of coverage of the roof is larger, such as in densely populated urban, commercial, and industrial areas [16-19]. There are different types of green roofs regarding their implementation and details, but in general, these types of roofs (Figure 1) are composed of nether components from top to bottom: vegetation (landscape materials), growing medium (substrate), filter, drainage material (moisture retention), root barrier, water proofing membrane, insulation layer, and structural layer [20,21].

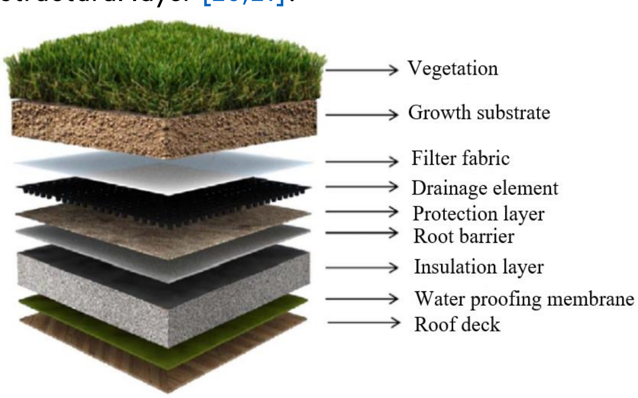

Fig. 1. Green roof components [21].

Different plants can grow on green roofs. Their limitations include climate, structural design, and maintenance budget. However, the depth of the cultivation environment affects the establishment of these plants. The vegetation should be able to grow in the climate of that area and survive adverse environmental conditions, reduce erosion, and prevent weed growth. Teemusk and Mander (2007) investigated the stormwater retention potential and runoff water quality of a Light Weight Aggregate (LWA)-based green roof in Estonia. The studied green roof effectively retained light rain, and the retention for 2.1 mm rainfall was 85.7%. In the case of a heavy rainstorm (12.1 mm), the green roof could delay the runoff for up to half an hour but could not fully retain it. There are two types of melting of a green roof: the melting of the snow cover and the melting of the frozen water in the substrate layer. The snow cover melted fast, but the green roof nevertheless prolonged the runoff to a longer timescale than that of the reference roof. The quality of the runoff water varied depending on the character of the runoff and the pollutants accumulated on the roof. [22]. Stovin (2010) showed that the green roofs had significant potential for controlling and managing urban showers. In the spring of 2006, the average retention volume was 34%, and the average peak flow was reduced by 57% using green roofs [23]. An investigation [24] of the hydrological processes in green roof systems for 29 months continuously on four green roof surfaces using different soil factors showed that different properties of moisture volume constantly depended on the characteristics of the bed and the presence of vegetation. Lee et al. (2013) identified how to improve building runoff mitigation through quantitative analysis of an extensive green-roof system. The results indicated that the extensive green roof had a high water-retaining capacity response to rainfall of less than 20 mm/h. As the rainfall intensity increased, the water-retaining capacity decreased. The catchment efficiency of an extensive green roof ranged from 0.44 to 0.52, indicating reduced runoff comparing with the efficiency of 0.9 for a concrete roof. Therefore, extensive green roofs are an effective stormwater best-management practice, and the proposed parameters can be applied to an algorithm for rainwater-harvesting tank design [25]. Vijayaraghavan et al. (2014) showed that green roof substrate was the main component to alter the quality of runoff. Their investigation raised the possibility of using a mixture of low-cost inorganic materials to develop a green roof substrate. Each of the materials used had different characteristics, and hence, a mix of these materials was desirable to develop an optimal green roof substrate. Eighteen different substrate mixes were prepared using a factorial design. And a detailed examination indicated that mix-12 exhibited desirable characteristics of green roof substrate with low bulk density (431 kg/m3), high water holding capacity (39.4%), air-filled porosity (19.5%), and hydraulic conductivity (4570 mm/h). It also provided maximum support to Portulaca grandiflora (380% total biomass increment) over one month of growth [26]. Lee et al. (2015) constructed and operated pilot-scale green roof assemblies in an urban setting. From a stormwater management perspective, green roofs were 42.8–60.8% effective in reducing runoff for a 200 mm soil depth and 13.8–34.4% effective in reducing runoff for a 150 mm soil depth. By using Spearman rank correlation analysis, high rainfall intensity was shown to have a negative relationship with delayed occurrence time, demonstrating that the soil media in green roofs did not efficiently retain rainwater. Increasing the number of antecedent dry days could help to improve water retention capacity and delay occurrence time. From the viewpoint of runoff water quality, green roofs could be regarded as the best management practice by filtration and adsorption through growth media (soil) [27]. Rocha et al. (2021) compared differently vegetated green roofs planted with xerophytic plant species and biocrusts vegetation. A particular focus was their ability to hold water during intense storm water events and also the quality of the harvested rainwater. Six test beds with different vegetation compositions were used on the roof of a building in Lisbon, Portugal. Regarding storm water retention, the results varied depending on the composition of the vegetation and the season. As for water quality, almost all the parameters tested were higher than the Drinking Water Directive from the European Union (EU) and Word Health Organization (WHO) guidelines for drinking-water quality standards for potable water. Based on the results, bio-crusts and xerophytic vegetation are viable green roof typologies for slowing runoff during stormwater events [28]. Therefore, in this study, the effect of surface layer materials using shards of bricks and grass for green roofs has been studied at rainfall rates of 45, 55, and 65 mm per hour with a constant slope of 5%, on the quantity and quality of drainage water on a green roof. For this purpose, the volume of water stored and drained from the green roof at different times and intensities of rainfall was measured, and the results were analyzed. The effect of the type of treatment used on the green roof on the electrical conductivity of the drain water was also investigated.

2. Materials and methods

This research was conducted as a field experiment in the hydraulic laboratory of the Agriculture Faculty in Zanjan University. The altitude of the region is 1594 meters above sea level, and its climatic condition is regarded as semi-arid. The experiments began in April 2018 and ended in August 2018. During 30-years (1971-2000) in different parts of Zanjan province, the average annual rainfall was about 336 mm, the temperature was 11° C, and the humidity was 54% [29].

2.1. Experimental design specifications and treatments of the experiment

The present study was conducted in a Completely Randomized Block Design (CRBD) and as a factorial experiment in two different treatments in three different raining intensities. The design factors included a green roof covered with brick shards and cultivated soil (grass). The rain simulator machine used in this research (Figure 2) consisted of a raining surface with 500 nozzles, and its height was 280 cm above the ground. The machine could produce droplets of three millimeters as the diameter in different raining intensities (about 120 mm/h). The experiments were conducted in three different raining intensities (45, 55, and 65 mm/h) with a 24-hour rainfall in returning periods of 5, 10, and 25 years in Zanjan of a cold and arid climate. Table 1 shows the characteristics of the experiments performed in the present study.

Table 1. Characteristics of the experiments performed.

Test	Type of modifier	Raining intensities (mm/h)
1		45
2	Small bricks	55
3		65
4		45
5	Grass	55
6		65

All the treatments were performed at a constant slope of 5%. According to Figure 3, a metal box with the dimensions of 100×80×90 cm was used to create a green roof in this research. The green roof consisted of three layers: the first layer was the drainage with the thickness of 10 cm filled with gravel, the second layer contained brick shards with a thickness of 12 cm, and the third layer was comprised of vegetation (grass) with a thickness of 20 cm on the brick shards. The inner wall of the trench was welded and sealed using iron pieces to increase the holding and load-bearing capability of the materials used in the green roof profile. Furthermore, to prevent the creation of preferential current at the contact edge of the soil and the wall of the profile, cotton fabric was used to cover the walls before putting the materials inside the profile. The drainage pipes used in the experiments were plastic pipes with a 110 mm diameter, which created holes with a diameter of 4 mm at intervals of 15 mm.

Fig. 2. Rain simulator machine.

Fig. 3. Types of modifiers used in green roof.

2.2. Measurement of qualitative parameters

In the present study, the measurements were performed every 10 hours so that the tested variables had enough time to drain the gravity water in the profile. Disposable containers were used to determine the amount of drainage, which was measured in a graduated cylinder after collecting. Also, the parameters were measured every 10 minutes to make a graph of the drained water. To measure the volume of the stored water, the following water balance equation was used:

$$S=I-O \quad (1)$$

In this equation:

S: the volume of stored water,

I: the volume of input water to the green roof

O: the volume of drained water from the green roof.

The electrical conductivity and acidity of the water from the green roof were measured using an EC meter and a pH meter machine, model proline b 250. Accordingly, during the test period, the drains in each experiment were sampled and the acidity and electrical conductivity of the drains were measured using 1 and 1.5-liter bottles made of polyethylene terephthalate (PET). Finally, the results of electrical conductivity were corrected using the temperature correction coefficient according to Equation (2).

$$EC_{25c} = EC_{tc} / (1+0.02\ (T - 25) \quad (2)$$

Equation (2) shows the EC standardization equation (electrical conductivity of water in Micro-Siemens/Centimeter and water temperature in

Celsius). In this regard, EC_{25c} is the salinity of the water at 25°C, EC_{tc} is the salinity of the water at laboratory temperature, and T the temperature of water at the time of testing [30].

2.3. Statistical analysis

The statistical analysis was performed in a Completely Randomized Design (CRD) as a three-factorial experiment since the conditions in all the experiments were the same. For doing statistical analysis, Minitab 16 software was used to test the data. This software is known as specialized statistical software for controlling quality, accounting, and raw data analysis and is used in many large and small industrial units [31]. The following indicators were calculated to evaluate the treatments in this study:

- Determining an appropriate treatment for the green roof
- Determining the best treatment in terms of water absorption and retention
- Determining the maximum and minimum volume of runoff and drainage water from rainfall at 45, 55, and 65 mm per hour
- Determining the effective treatment on the EC and pH of the drainage water

3. Results and discussion

Analyzing and investigating the variance of effects of the experimental factors on the volume of the stored and drainage water shows that the main effects, i.e., corrector type, rainfall intensity, and time, are statistically significant at the level of 1%. Also, mutual interaction effects between the correctors on rainfall intensity, also rainfall intensity on time, the volume of stored water parameter was significant; on the other hand, the mutual interaction effects of the correctors on rainfall intensity and rainfall intensity on time and the triple interaction of the factors were not statistically significant. Therefore, significant factors were investigated, including the extent and impact ability method of the volume of stored and drainage water parameters. To study the effect of time on the volume of the stored and drainage water from the green roof, the data were measured at three different times of 10, 20, and 30 minutes (Figure 4). It showed that the volume of stored water on the green roof decreased, and the volume of the drainage increased. Also, the differences in performance in the shard of brick and grass bed were maximum in 10 minutes, and this difference decreased by increasing the data measurement time. The highest performance difference between the two green roof correctors was related to the volume of drainage water in 10 minutes, which was due to the high absorption of grass at the beginning of rainfall.

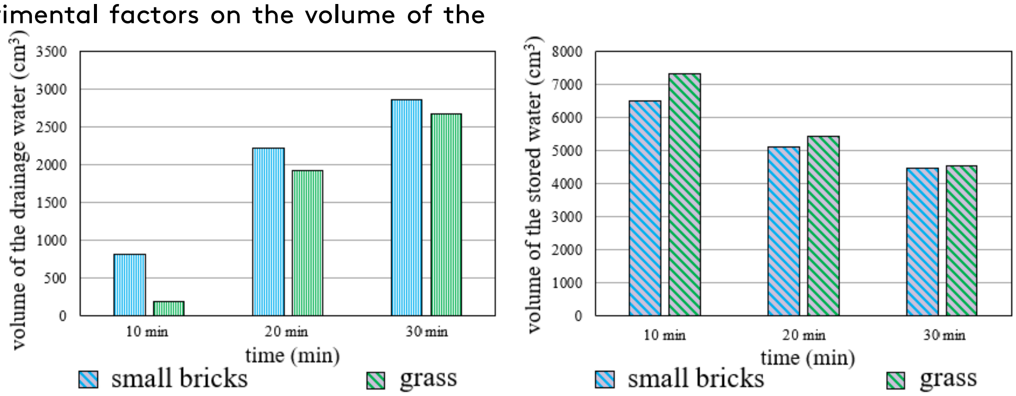

Fig. 4. The effect of time treatments on the volume of stored and drainage water.

Rainfall intensity is another parameter studied in the present study. Thus, the volume of stored and drainage water from both types of correctors, shards of bricks and grass, were measured at 45, 55, and 65 (mm/h). By increasing rainfall intensity for both studied correctors, stored and drainage water volume parameters increased, and the effectiveness of these parameters varied in different correctors. Figure 5 shows that by increasing rainfall intensity, the percentage of the stored water in the shards of bricks is higher than the grass type in the green roof. While the rate of change of drainage water is more against the intensity of precipitation in the grass. Therefore, choosing and designing a desirable green roof depends on the range of changes in rainfall intensity in that area. Thus, it is necessary to consider this factor in designing and implementing green roofs.

A comparison of the average performance in both types of correctors in the green roof in Figure 6 shows that the volume of the stored water in the grass corrector is higher; so, if shards of bricks are used, 69% of the rainfall will be stored and 31% is drained. However, adding grass to the green roof increases the volume of stored water to 78% and reduces the volume of drainage water to 22%. Nawaz et al. (2015) also stated in their research that the volume of stored water in the grass corrector was more than other materials [32].

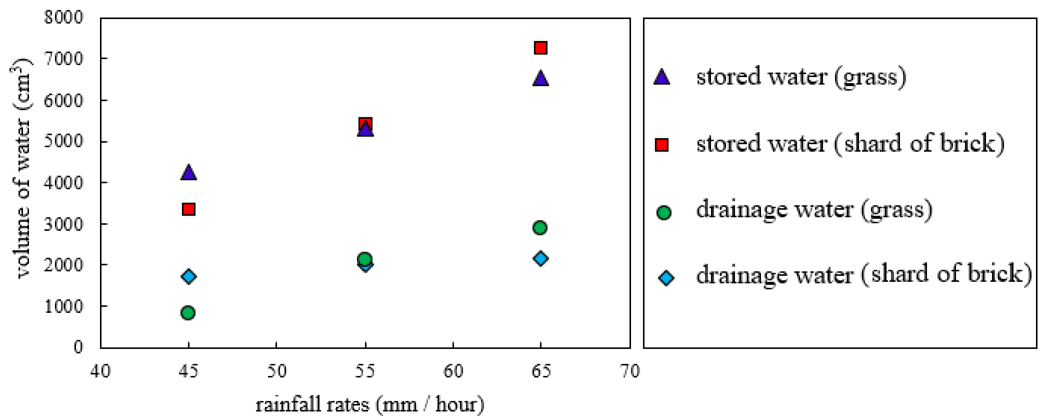

Fig. 5. The effect of rainfall intensity treatments on the volume of stored and drainage water.

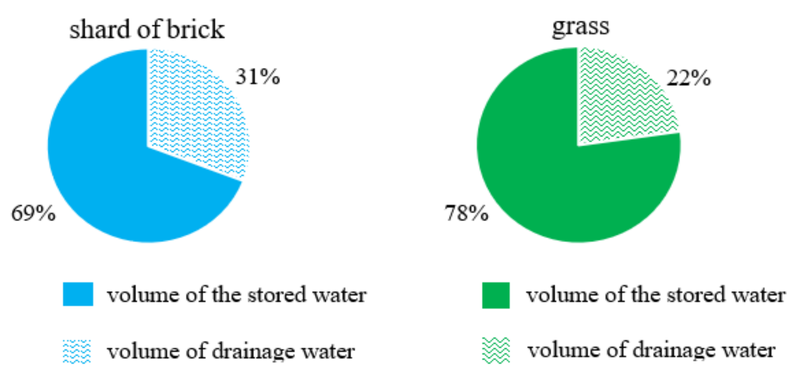

Fig. 6. The effect of corrector type on the volume of stored and drainage water.

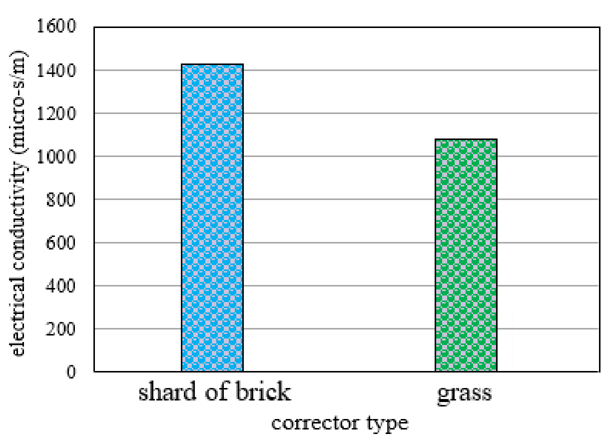

Fig. 7. The effects of both correctors on the stored and drainage water.

Figure 7 shows the effects of corrector treatments on the electrical conductivity of the drainage. It is observed that the volume of salinity and electrical conductivity in the shards of bricks corrector without grass is higher than the corrector with grass so that the presence of grass on the green roof reduces the volume of electrical conductivity by 32%.

4. Conclusions

In this study, the following results were obtained by examining the amount of drainage and stored water in green roofs with different materials.

1. Regardless of the type of material used in the green roof, the amount of water stored in the green

roof decreased with increasing time, and the number of drained water increased.

2. A comparison of the average performance of the shard of brick and grass modifiers for green roofs showed that the amount of water stored in the grass modifier was higher, and if shards of brick were used, more water would be drained.

3. Due to the high absorption of grass at the beginning of the rainfall, the functional difference between the two cultivars studied in the early times was maximum.

4. With increasing rainfall intensity, the percentage of increase in the water stored in the shard of brick was higher than grass. While the amount of change of drainage water versus the rainfall intensities was more in the grass.

5. By adding grass to the green roof, the amount of water stored increased from 69% to 78% for the shards of brick.

6. Also, the presence of grass on the green roof reduced the amount of electrical conductivity by 32% compared to the shards of bricks alone.

Finally, the following suggestions are recommended for future studies. It is suggested to study the effect of the wind parameter and the height of buildings to develop knowledge of the factors affecting the performance of green roofs. Also, according to the results of the present study and similar studies, more research should be done on the effect of height and the percentage of green roof grass density.

- Cadmium concentration from 0.2 to 50 mg/L, the adsorption rate increased from 9 to 1610 mg/kg, and the percent adsorption decreased from 88 to 63 percent; still, at the fifth stage, these changes declined and the adsorption rate increased from 6.8 to 450 mg/kg, and the percent adsorption decreased from 64 to 17 percent.
    - The adsorption data showed that the pseudo-first-order and Freundlich adsorption models best described the adsorption rate of cadmium by riverine sediment, respectively, for kinetics and equilibrium conditions.

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