Temporal Changes of Green Roofs Retention Capacity

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Abstract. Green roofs experience an evolution over the years of physical and chemical properties of the substrate layer that may lead to substantial changes in their hydrological behavior. This study, benefiting from a 5-years monitoring period, aims at assessing changes in the retention capacity of two experimental green roofs (GR1 and GR2), located in Southern Italy and different in drainage layer, by comparing pairs of similar rainfall-runoff events which occurred respectively in 2018 and early 2019, one year after installation, and in 2022. To this end, once identified the retention capacity of each, differences among similar events occurred four years apart were assessed and compared for the two green roof configurations to detect: possible changes in their hydrological performance, the configuration most affected by aging and the evolution of their differences over time. The results obtained so far suggest a general decay of the green roofs retention capacity with some differences according to the drainage characteristics. GR1, with a drainage layer made by 5-cm depth expanded clay, reported a 79% reduction of retention capacity while GR2, with a drainage layer made by MODI' plastic panel filled with expanded clay, experienced a reduction of about 53%. Differences between the two green roof configurations also increase due to aging effects because the substrate, initially crucial in the retention dynamics, seems affected by a progressive performance loss. Conversely, the drainage layer, that appears to play a secondary role in the early operational period, becomes determinant in the medium observation period.

Keywords: Green roofs · Retention capacity · Aging

1 Introduction

During the last decades, the combined effects of urbanization and climate change led to the need for sustainable drainage strategies, capable of supporting the traditional technologies in the management of flooding phenomena at the catchment scale [1].

Among the different solutions, there are certainly green roofs, vegetated roofs able to mitigate volumes and flow rates through the implementation of two fundamental processes: retention and detention [2, 3].

The retention capacity of green roofs depends on numerous factors such as climatic conditions, design choices, technological characteristics and aging [4, 5]. In particular,

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the evolution of the physical and chemical properties of the substrate can significantly influence the hydrological performance of these infrastructures [6, 7]. However, due to the need for long monitoring periods of experimental sites, few are the studies that focused on assessing aging effects on the green roofs hydrological response and their results are often conflicting [8, 9].

Therefore, starting from a monitoring activity of about five years (2017–2022), this study aims at assessing the retention capacity of two experimental green roofs [10] by comparing rainfall-runoff events, similar for precipitation depth and initial soil moisture conditions, which occurred respectively in 2018 and early 2019, one year after installation, and in 2022.

2 Materials and Methodology

2.1 The Experimental Site

Two extensive green roofs test beds were installed at the Maritime and Environmental Hydraulic Laboratory of the University of Salerno in January 2017. Each one of them has an area of 2.5 m^2 and a total thickness of 15 cm. They are made up of a vegetation layer, a substrate layer and drainage layer with a filter mat of non-woven fabric interposed between the latter two. The vegetation layer consists in succulent plant called Mesembryanthemum, typical of Mediterranean areas. The 10-cm depth substrate layer consists of a soil mix made of peat, zeolites, coconut fibres and bio stimulant algae as fertilizer. The two green roofs differ for the 5-cm depth drainage layer. In fact, for one of them (GR1) it is made up by expanded clay while for the other (GR2) it is made up of a commercial plastic trays (MODI') with truncated cone shape concavity filled with expanded clay. Laboratory experiments aimed at the characterization of the retention capacity of these drainage layers pointed out that GR2 system is than featured by a moderate larger retention capacity (about 18%) if compared to GR1. The experimental site is continuously monitored by a weather station that includes tipping bucket rain gauge, hygrometer, pyranometer, anemometer and four FDR probes (Reflectometry in the Frequency Domain) located at opposite ends of the green roofs to measure the soil moisture content. Since these values could be affected by the presence of roots in the substrate layer, they are appropriately calibrated with relationships function of the root growth stage. The runoff generated by green roofs is measured at 5-min time steps (Fig. 1).

2.2 Methodology

The analyses required the identification of six rainfall-runoff events recorded in the year 2022 (EV_{2022}_h1; EV_{2022}_h2; EV_{2022}_h3; EV_{2022}_h4; EV_{2022}_h5; EV_{2022}_h6) to be compared with six events selected from the database of the years 2018–2019, similar in terms of rainfall depth and initial soil moisture content, SMC (EV_{2018}_h1; EV_{2018}_h2; EV_{2018}_h3; EV_{2018}_h4; EV_{2018}_h5; EV_{2019}_h6).



Fig. 1. Experimental site evolution: a. green roofs in 2018; b. substrate in 2018; c. green roofs in 2021; d. substrate in 2021.

Moreover, for each event identified the cumulative runoff was measured and the retention capacity (RC), representative of the hydrological performance of the green roofs, was calculated as follows:

$$RC(\%) = \left(1 - \frac{R}{P}\right) \cdot 100 \tag{1}$$

where:

R = runoff depth (mm)
P = precipitation depth (mm)

The similarity criterion made it possible to identify six pairs of events for both the green roofs (EV_{2022}_h1-EV_{2018}_h1; EV_{2022}_h2-EV_{2018}_h2; EV_{2022}_h3-EV_{2018}_h3; EV_{2022}_h4-EV_{2018}_h4; EV_{2022}_h5-EV_{2018}_h5; EV_{2022}_h6-EV_{2019}_h6).

Tables 1 and 2 show respectively the characteristics of the rainfall-runoff events selected from the databases relating to the years 2022 and 2018–2019. It is possible to notice that, under the same precipitation event, GR1 and GR2, which differs for the drainage layer, exhibit a different behavior in terms of runoff and therefore of retention capacity.

Table 1. Characteristics of rainfall-runoff events registered in 2022.

2022 Events	P (mm)	SMC GR1 (%)	SMC GR2 (%)	RC GR1 (%)	RC GR2 (%)
EV_{2022}_h1	0.60	33.15	28.39	87	89
EV_{2022}_h2	1.27	34.18	31.43	80	65
EV_{2022}_h3	5.33	30.84	29.16	82	79
EV_{2022}_h4	8.00	32.93	27.78	58	66
EV_{2022}_h5	15.49	31.88	31.31	15	25
EV_{2022}_h6	35.56	30.89	28.62	23	26

Table 2. Characteristics of rainfall-runoff events registered in 2018–2019.

2018 Events	P (mm)	SMC GR1 (%)	SMC GR2 (%)	RC GR1 (%)	RC GR2 (%)
EV_{2018}_h1	0.51	27.18	28.58	100	100
EV_{2018}_h2	1.78	29.17	31.24	87	82
EV_{2018}_h3	5.84	20.76	21.19	85	81
EV_{2018}_h4	7.11	25.06	27.01	84	80
EV_{2018}_h5	13.46	28.92	31.20	49	51
EV_{2019}_h6	32.00	11.59	15.05	63	66

It can be observed that the selected precipitations are characterized by rainfall depths ranging from 0.60 mm to 35.56 mm. These are events of mild or moderate intensity, for which the effectiveness of sustainable drainage systems should achieve important results. This study foresaw three main levels of analysis: the assessment of the differences between the retention capacities (RC) of GR1 and GR2 obtained under similar rainfall events occurred during the whole period of observation; the identification of the configuration most affected by the aging effects; the study of the evolution of the hydrological differences between GR1 and GR2. The following relationship was used to assess the differences between the retention capacities of GR1 and GR2 between 2018 and 2022 (DR_{aging}):

$$DRxaging(\%) = \left(\frac{RCx2022 - RCx2018}{RCx2022}\right) \cdot 100 \tag{2}$$

where:

RCx2022 = retention capacity of infrastructure "x" (GR1 or GR2) in 2022 (%).
RCx2018 = retention capacity of infrastructure "x" (GR1 or GR2) in 2018 (%).

In order to assess, instead, the differences between GR1 and GR2 depending on the year of observation and thus on the aging stage ($DR_{drainage}$), their relative difference was computed as follows:

$$DRydrainage(\%) = \left(\frac{RCyGR2 - RCyGR1}{RCyGR2}\right) \cdot 100 \quad (3)$$

where:

RCyGR2 = retention capacity of GR2 in the "y" year (2018 or 2022) (%).
RCyGR1 = retention capacity of GR1 in the "y" year (2018 or 2022) (%).

3 Results

The results are reported in Table 3 and in Fig. 2. As regards the evaluation of the effects of the aging phenomenon on the retention capacity (DR_{aging}), a substantial decrease of the hydrological performance can be observed for both green roof configurations (GR1 and GR2).

Furthermore, GR1 seems to be more affected by the phenomenon of aging. The latter, in fact, registered an average reduction in retention capacity of approximately 79% while GR2, which differs only for the drainage layer made by MODI' plastic panels, of about 53%.

Table 3. Comparison of retention capacity under the aging and drainage effects.

	RAIN (mm)		RC_{GR1} (%)		RC_{GR2} (%)		DR_{aging} (%)		$DR_{drainge}$ (%)	
	2018	2022	2018	2022	2018	2022	GR1	GR2	2018	2022
EV_h1	0.51	0.60	100	87	100	89	−15	−12	0	3
EV_h2	1.78	1.27	87	80	82	65	−9	−26	−6	−23
EV_h3	5.84	5.33	85	82	81	79	−3	−3	−5	−4
EV_h4	7.11	8.00	84	58	80	66	−43	−22	−5	11
EV_h5	13.46	15.49	49	15	51	25	−230	−105	3	40
EV_h6	32.00	35.56	63	23	66	26	−174	−154	5	12
						Mean	**−79**	**−53**	**−1**	**6**

According to the characteristics of the events selected in 2018, during the early operational period, the differences between GR1 and GR2 are almost undetectable with GR1 performances on average moderately higher than GR2 [5]. This is confirmed by the 2018 $DR_{drainage}$ values shown in Table 3 that, even if for a modest number of events, indicates that in 2018 the RC differences between the two roofs were on average equal to 1%. Provided GR1 and GR2 only differ for the drainage layer properties, this seems to be reasonably attributable to the fact that the drainage layer does not play a fundamental role in the retention process, at least in the first operational period. However, in 2022,

five years after the experimental site set up, the hydrological performance appears very different. The differences between the two roofs increased up to about 23% in the case of "EV_h2" and 40% in the case of "EV_h5" with an average value of the differences equal to 6% in favor of GR2.

Overall, the results would lead to think that the evolution of the chemical and physical characteristics of the substrate brings to a double effect. The first and most noticeable one is the reduction of the retention capacity of the green roofs, more specifically related to a progressive performance loss of the substrate layer. Whereas, the second is the relevance of the drainage layer in the medium observation period, not appreciable during the early stages of the infrastructure where the retention effect of the substrate is undoubtedly predominant.

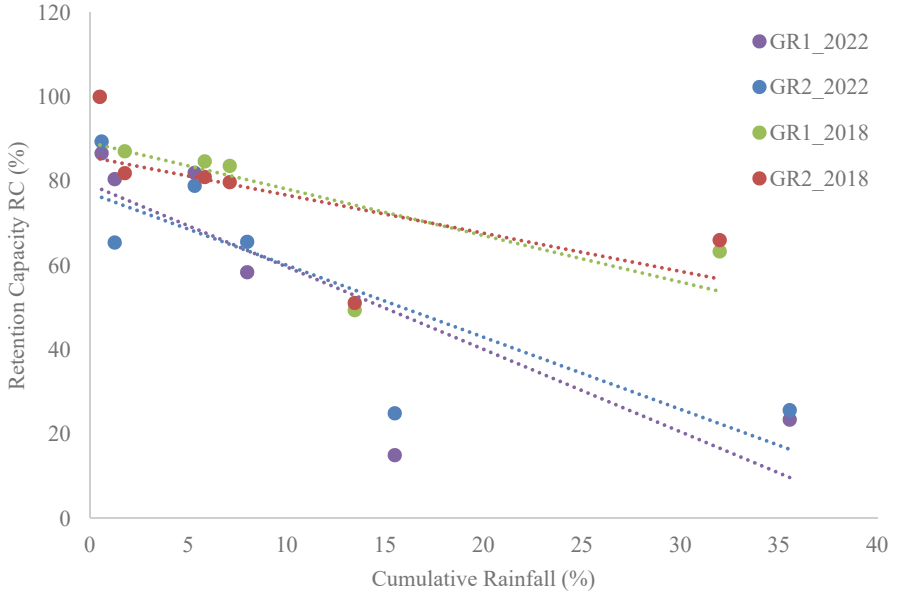


Fig. 2. Green roofs retention capacity as a function of rainfall depth in the observation years.

4 Conclusions

This research work aimed at assessing the evolution of the hydrological performance of two experimental green roofs, different for the drainage layers properties, through a 5-years monitoring period of the meteorological characteristics and the runoff at a small temporal resolution.

The results obtained so far suggest a physiological decay of the retention capacity of green roofs, certainly attributable to a change in the chemical-physical characteristics of the substrate. The characteristics of the drainage layer seem to influence the response of these infrastructures to the effects of aging. In fact, GR1 registers on average 79% reductions in retention capacity over time while GR2 53%.

The differences between GR1 and GR2 also increase due to aging effects because over time the substrate, the main actor in the management of retention dynamics in the early stages of the infrastructure's life, is affected by a progressive reduction of its potentiality that makes the role of the drainage layer increasingly decisive over time.

The drainage layer of GR2 still confirmed to have the highest performance. A more extensive study, aimed at analyzing the evolution of green roofs based on a larger number of rainfall-runoff events, is certainly necessary for confirmation of the quantitative assessments set out so far.

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