Impacts of monoculture and mixed vegetation on green roof hydrological function

Impacts de monocultures et de végétations variées sur la rétention hydraulique et les débits maximaux de ruissellement

Joel Lönnqvist*, Jonathan Hjelm*, Godecke-Tobias Blecken*, Maria Viklander*

*Urban Water Engineering, Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology
971 87 Luleå, Sweden (joel.lonnqvist@ltu.se)

RÉSUMÉ

Une couverture végétale dense est habituellement recherchée pour répondre aux attentes esthétiques associées aux toitures végétalisées. En conséquence, les plantes tolérantes au stress de genre Sedum ont été traditionnellement préférées pour les toitures végétales extensives. Cependant, la faible consommation en eau et la faible biomasse racinaire des Sedums pourraient s'avérer sous-optimales pour la fonction hydrologique de ces toitures en comparaison à une végétation qui aurait des besoins différents. Cette étude s'intéresse aux performances hydrauliques de quatre mélanges de plantes groupés suivant la théorie des stratégies CSR de Grime, d'une monoculture de Sedum et d'un toit de contrôle non végétalisé. Les débits de ruissellement provenant des différentes toitures ont été mesurés et enregistrés durant 7 pluies (3.4–8.4mm) d'automne (températures entre 6 et 13 ˚C). Les résultats n'ont pas mis en évidence de relations entre la couverture végétale et la rétention hydraulique des toits. Les toits végétalisés avec des mélanges de plantes tolérants au stress avaient, dans l'ensemble, la plus forte rétention hydraulique. Les toits végétalisés avec la monoculture de Sedum avaient la plus haute couverture végétale mais la plus faible rétention hydraulique.

ABSTRACT

A dense vegetation cover is usually desired to fulfil aesthetical expectations of green roofs, and therefore stress tolerant Sedum vegetation has traditionally been favoured for extensive green roofs. However, Sedum species' low water use and low root biomass could prove suboptimal for the hydrological function of green roofs compared to vegetation with different water use strategies. This study evaluated the hydrological performance of four different vegetation mixtures based on Grime's C-S-R life strategies and compared their performance to a Sedum monoculture and bare substrate. Runoff from seven rainfall events (3.4–8.4 mm) was recorded during one autumn season when temperatures were getting lower (6–13˚C). The results showed no relationship between vegetation cover and retention, and the roofs planted with a mixture of stress tolerant species showed the greatest overall retention. Green roofs planted with the Sedum monoculture had the greatest vegetation cover but the lowest mean retention.

KEYWORDS

(green roof, plant selection, vegetation cover, stormwater retention, peak flow reduction, plant strategy)

1 INTRODUCTION

1.1 Vegetation and stormwater management

1.1.1 Plant selection for green roofs

Since rooftops are stressful environments stress tolerant species have traditionally been chosen for green roof vegetation (Monterusso et al., 2005). Sedum species have been extensively used due to their high survival during droughts, their shallow root systems that tolerate limited substrate depths and their ability to form a dense plant cover (Dunnett & Kingsbury, 2004). I has been hypothesized that green roofs with high vegetation cover are better for runoff retention (Dunnett et al., 2008). However, Sedum have low transpiration rates; thus their ability to restore the water holding capacity of the substrate between rain events should be considered limited (Nagase & Dunnett, 2012). In general, taller plants with higher root biomass increase evapotranspiration through interception, and increase storage capacity of the substrate (Dunnett et al., 2008). Consequently, there may be alternative vegetation compositions more suitable than Sedum if stormwater retention of a green roof is the main objective of a green roof (Farrell et al., 2013).

1.1.2 C-S-R groups and aim

The universal adaptive strategy theory suggests three different categories for plant survival, where each group makes trade-offs between growth, maintenance and reproduction (Grime, 1977). The groups react differently to stress and disturbance and have different resource and water use (Grime, 1977). Under favourable conditions, competitive vegetation can grow fast and create biomass, leding to increased evapotranspiration. Stress tolerant vegetation instead, sustain the vegetation cover during unfavourable weather when other vegetation starts to wilt. After most vegetation has wilted and bare substrate has been created, ruderal propagules remain in the substrate, ready to recolonize the roof and re-establish plant cover. We hypothesized that vegetation mixtures with complementary life strategies would be more resilient to change thus improving survival during demanding conditions, when compared with Sedum monocultures. Thus, the aim of this study was to explore the role of the vegetation cover, plant mixtures and different vegetation survival strategies (CSR) on green roof hydrological performance.

2 METHODS

Roof modules (size 2x1 m) were constructed in Luleå, northern Sweden. The modules consist of six groups with five replicates each. The plant species compositions of these groups were selected based on their CSR-strategy and previous green roofs plant surveys in the surrounding region. The different groups Competitive (C), Stress tolerant (S) and Ruderal (R) were planted with five different species each. A mixed group contained all 15 species of the other vegetation strategies. A *Sedum acre* monoculture and bare substrate group were included. The roofs were planted in summer 2017. Vegetation development was documented by photographing each module from above and analyzing the pictures for vegetation cover. Runoff and precipitation were monitored and loggged with 5-minute resolution. Data from autumn 2018 is presented in the following.

3 RESULTS

3.1 Vegetation cover and hydrological function

The vegetation cover of the different vegetated module groups was generally low, with a total mean cover of 24%. The only group with a significantly different mean vegetation coverage was the *Sedum* monoculture (Figure 1). For the seven included rain events there were no relationships between vegetation cover and (i) stormwater volumes (Figure 2 left) and (ii) peak flows (Figure 2 right).

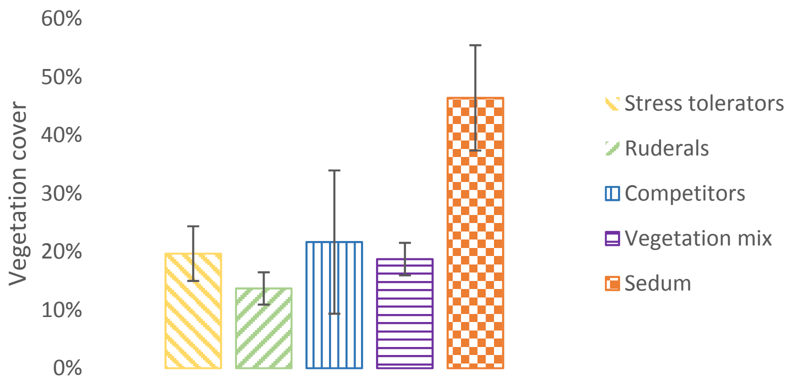

Figure 1. Mean vegetation cover of the different vegetated modules (n=5).

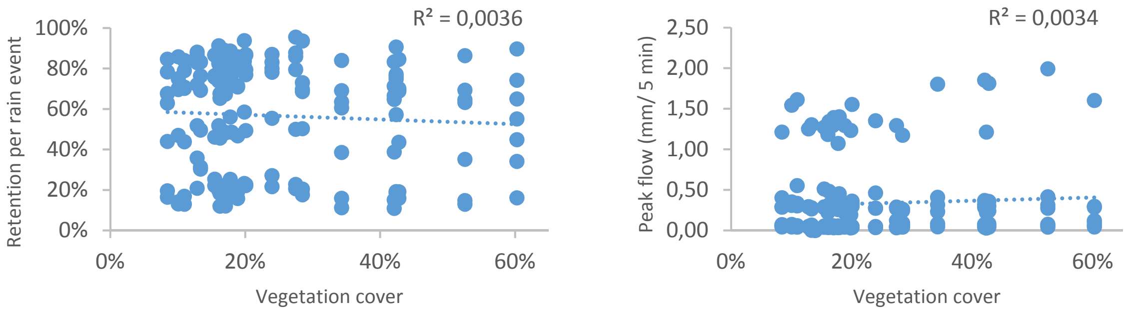

Figure 2. Vegetation cover and retention per rain event (left) and peak flow (right).

3.2 Rainfall retention per rain

3.2.1 Rain events and peak flows

Due to the small volume and intensity of most observed rains, the events generated relatively low peak flows with no significant differences between the different vegetation treatments. For the largest rain event (Figure 3) there was a significant difference between the bare substrate, the Sedum monoculture and the other vegetation groups in the peak flow generated (one-way ANOVA, α=0.05). There were no significant differences in peak flows generated by the competitive, stress tolerant ruderal and mix groups.

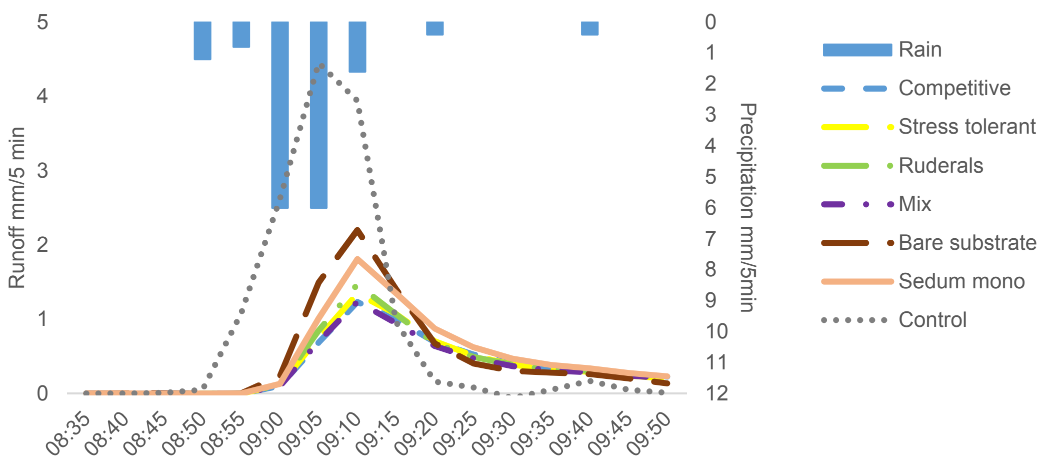

Figure 1. Hydrograph of rain event no. 2 with total rainfall volume of 8.4 mm and three antecedent dry days

3.2.2 Vegetation groups and rainfall retention

The stress tolerant group had the highest mean retention of 62% followed by the mixed strategy group (59%), competitors (58%), ruderals (54%) and substrate only (53%). The Sedum monoculture had the lowest mean retention of 51%. There was no significant difference (one-way ANOVA, p=0.95) in mean rainfall retention. For all rains, the only significantly different group was the tin roof control (Table 1). However, when looking at separate rain events there were differences in retention among the groups, with consistently greater retention for the stress tolerant group and more variable retention in the other groups.

Table 1. One-way ANOVA and Tukey's pairwise comparisons of retention for the different rain events (α=0.05). Significantly different means have different letters where letter A has the greatest retention and D the lowest.

Rain no. (mm)	1 (6.4)	2 (8.4)	3 (3.4)	4 (3.4)	5 (4.2)	6 (3.8)	7 (6.8)	All rains
Stress tolerant	A	A	A	A	A	A	A	A
Ruderals	A	AB	C	BC	A	C	B	A
Competitors	A	A	ABC	BC	A	BC	A	A
CSR mix	A	A	AB	AB	A	ABC	A	A
Sedum mono	A	B	C	C	A	D	B	A
Substrate only	B	AB	AB	BC	A	AB	AB	A
Control	C	C	D	D	A	E	B	B

4 DISCUSSION

Despite the Sedum monoculture having the greatest vegetation cover, it did not show the greatest stormwater retention. This could be due to Sedum's low stature, decreasing the possibility of interception and low evapotranspiration due to the drought adapted low water use. The root mass of Sedum is small compared to grasses and forbs found in the other vegetation groups. The more developed roots systems allow for a more complex substrate and greater water holding capacity. Stress tolerant vegetation consistently showed relatively high stormwater retention compared to the other groups. This group contains sturdy species, capable of surviving drought but also a grass species capable of producing significant amounts of biomass and root systems. This paper presents preliminary results of a longer-term study. So far, only a limited amount of events during autumn have been analysed when evapotranspiration rates should be low due to cool air temperatures. Continued measurements throughout the growing season with a higher resolution may show greater differences between vegetation groups. More rainfall events with varying intensities will also add to the story.

CONCLUSION

The investigated rain events took place during a season that is unfavourable for the vegetation and temperatures and evapotranspiration was low. Most of the differences in stormwater retention between the vegetation groups were small, but the stress tolerant group had a consistently high performance. Although the Sedum monoculture had the greatest vegetation cover, it had lower mean retention than the bare substrate. The mean maximum flow reduction was insignificant for the smaller rain events. However, the larger rain events showed some differences, where the different vegetation groups performed better than the Sedum monoculture and the bare substrate. The vegetation groups planted with mixtures of species had lower vegetation cover than the Sedum monoculture, but probably had greater canopies and root structures, affecting the water holding capacity of the substrate. The roofs planted with mixtures containing all three plant survival strategies did not have the highest retention as hypothesized. More measurements of varying rain events will be made to make further conclusions.

LIST OF REFERENCES

Dunnett, N., & Kingsbury, N. (2004). *Planting green roofs and living walls*. Cambridge, UK: Timber press.

Dunnett, N., Nagase, A., & Booth, R. (2008). *Influence of vegetation composition on runoff in two simulated green roof experiments. Urban Ecosyst.*, *11*(4), 385–398.

Farrell, C., Szota, C., Williams, N. S. G., & Arndt, S. K. (2013). *High water users can be drought tolerant : using physiological traits for green roof plant selection. Plant and Soil*, *372*(1–2), 177–193.

Grime, J. P. (1977). *Evidence for the existance of three primary strategies in plants and its relevance to ecological and evolutionary theory.* Am. Nat.

Monterusso, M. A., Bradley Rowe, D., & Rugh, C. L. (2005). *Establishment and persistence of Sedum spp. and native taxa for green roof applications. HortScience*, *40*(2), 391–396.

Nagase, A., & Dunnett, N. (2012). *Amount of water runoff from different vegetation types on extensive green roofs: Effects of plant species, diversity and plant structure. Landsc. Urban. Plan.*, *104*(3–4), 356–363.