Potential Stormwater Mitigation by Green Roof Colonising Plants: Fast, Slow & Functional

Potentiel d'atténuation des eaux pluviales en fonction des caractéristiques des espèces colonisatrices des toitures végétalisées : rapides, lentes et fonctionnelles

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RÉSUMÉ

Les toitures végétales sont de plus en plus adoptées dans une optique de réduction du ruissellement des eaux pluviales en villes. La présence de végétation sur les toits permet d’augmenter la rétention de l’eau de pluie en asséchant les substrats suite aux évènements pluvieux. Pour optimiser la rétention d’eau et la survie des plantes, les espèces sélectionnées doivent présenter une forte consommation en eau post-précipitations et être tolérantes à la sécheresse entre les événements pluvieux. Les plantes qui colonisent naturellement les toitures végétales supplantent souvent les espèces introduites volontairement. Toutefois, l'influence de ces espèces sur la rétention des eaux pluviales est encore mal connue. Par conséquent, nous avons déterminé la consommation d’eau et la réponse à la sécheresse de neuf espèces colonisatrices communes et avons relié ces données aux caractéristiques des plantes. Nous avons émis l'hypothèse que des caractères rapides tels qu'un fort taux de croissance relatif (RGR; Relative Growth Rate) seraient associés à une consommation d’eau élevée et que des caractères lents tels qu'un faible RGR seraient associés à une tolérance à la sécheresse. Alors que les espèces dites rapides ont cédé face au déficit en eau, les espèces dites lentes ont maintenu leur statut hydrique en dessous du déficit hydrique. Ainsi, les espèces colonisatrices des toitures végétales présentant des caractéristiques rapides pourraient diminuer les eaux de ruissellement pendant et après les précipitations et les espèces lentes pourraient avoir une meilleure survie sur les toitures végétales exposés à la sécheresse. Un mélange d'espèces rapides et lentes pourrait alors améliorer la réduction des eaux de ruissellement et étendre la continuité de la végétation sur les toitures végétales.

ABSTRACT

Green roofs are increasingly being adopted to alleviate stormwater runoff in cities. Vegetation increases the rainfall retention of green roofs by drying out substrates following rainfall. To optimise retention and plant survival, species need to be high water users following rainfall and drought tolerant between rain events. Plants that naturally colonise green-roofs often out-compete intended plantings, however the influence of these species on stormwater retention is not clear. Therefore, we conducted a glasshouse experiment to determine the water use and drought response of nine common colonising species and related these to plant traits. We hypothesised that 'fast' traits such as high relative growth rate (RGR) would be associated with high water use and 'slow' traits such as low RGR would be associated with drought tolerance. This was supported by our results, as fast species had high water use and slow species maintained water status under water deficit. Green roof colonising species with fast traits could reduce stormwater runoff and slow species could have greater survival on green roofs. A mixture of fast and slow species could improve stormwater mitigation and maintain plant cover on green roofs.

KEYWORDS

Fast-slow; green roof; plant selection; stormwater; weeds

1. INTRODUCTION

Hard urban surfaces limit infiltration and increase the volume and peak flow of stormwater runoff, transporting contaminants and degrading receiving ecosystems (Fletcher et al. 2013). Green roofs can help mitigate stormwater runoff by retaining rainfall in substrates (Monterusso 2004) and releasing it to the atmosphere via evapotranspiration. Plants with high evapotranspiration can increase substrate storage capacity but plants also need to tolerate drought between rain events to ensure survival and maintenance of cover on green roofs (Farrell et al. 2012).

In the absence of regular maintenance, green roof plant communities change, and colonising species replace the original planting (Catalano et al. 2016). Wide ranges of plant species are known to colonise green roofs, forming remarkably dynamic communities with diverse functional traits and life-forms (see Catalano et al. 2016; Madre et al. 2014; Wolf and Lundholm 2008), however the influence of these species on stormwater retention is not clear.

In plant ecology, theoretical models such as the 'fast-slow' continuum could help predict the water use and drought resistance of green roof colonising plants. The 'fast-slow' continuum underpins trade-offs between growth, maintenance and regeneration that determine plant fitness (Reich 2014). Generally, 'fast' species are fast-growing whereas 'slow' species are slow-growing (Salguero-Gómez et al. 2016). Characteristically fast traits, such as high relative growth rate and transpiration, are favourable in resource-rich ecosystems; however, these traits become limiting under conditions of low productivity (Grime 2001).

On green roofs, it is likely that colonising species exhibit variation in terms of resource acquisition; allowing 'fast' and 'slow' species to coexist successfully (Huxman et al. 2008). Variation in species' resource uptake reduces competition for resources and facilitates coexistence; this complementarity may improve temporal stability in plant cover and consequently stormwater retention (Heim & Lundholm 2014). Therefore, it is likely that green roof colonising species will vary in their water use and drought response strategies and the 'fast-slow' continuum could predict their potential for survival and stormwater mitigation.

1.1 Aims, Objectives and Hypotheses

We aimed to determine the water use strategies and drought response of nine common green roof colonising plant species. We also determined whether their water use, and drought response related to their relative position on the 'fast-slow' continuum, determined by their relative growth rate. We hypothesised that 'fast' species would be higher water users under well-watered conditions and would be more sensitive to drought stress under water-deficit conditions than 'slow' species.

2 METHODS

2.1 Species Selection and Plant Establishment

Seeds of nine common green roof colonising species (Madre et al. 2014) were collected from across metropolitan Melbourne (-37.813863, 144.962353) and grown in pots filled with scoria-based green roof substrate (Farrell et al. 2012). Six replicate plants of each species were randomly allocated to well-watered (WW) or water-deficit (WD) treatments. Pots were weighed before and after watering to determine water loss between watering events and calculate daily evapotranspiration (ET). Pots were watered every second day; WW pots were watered to pot capacity and WD pots received 30% of their WW equivalent's water use over the intervening period (Farrell et al. 2014). At the end of the experiment, plant drought response was determined by measuring leaf relative water content (RWC) (Sade et al. 2015). A lower leaf RWC indicates greater drought stress (Hsiao 1973). Relative growth rate (RGR) (Hunt et al. 2002) was determined from the change in shoot biomass under WW conditions by harvesting six replicates of each species at the start and end of the experiment. The water deficit experiment ran from November 2016 to February 2017.

2.2 Data Analyses

One-way ANOVA was used to analyse differences in RGR, leaf RWC and ET between species within each treatment and within species between treatments. Simple linear regression was used to examine relationships between RGR and physiological response. Data was transformed where necessary for univariate normality. Statistical analyses were performed in R (R Core Team 2016).

3 RESULTS

3.1 Evapotranspiration and Plant Drought Response

Under well-watered (WW) conditions, *Trifolium repens* and *Lolium perenne* had the highest rates of daily evapotranspiration (Table 1). *Euphorbia maculata* was the lowest water user, followed by *Euphorbia peplus*. Except for *E. maculata*, all species significantly reduced water use under WD. *L. perenne* maintained the highest rate of transpiration under WD, followed by *Plantago lanceolata* and *T. repens*, while *E. maculata* and *E. peplus* had the lowest water use. Low water users maintained the highest leaf RWC under WD conditions. Whereas the highest water user (*L. perenne*) had the lowest leaf RWC under WD.

Table 1: Mean daily evapotranspiration (ET) under well-watered (WW) and water deficit (WD) conditions, and leaf relative water content (RWC) under water deficit (WD) with standard error shown in brackets. Bold *p* values indicate a significant difference between treatments.

Species	WW ET (g^{-1}/day^{-1})	WD ET (g^{-1}/day^{-1})	*p* value	WD Leaf RWC (%)
E. maculata	67.25 (5.25)	52.26 (4.38)	0.06	96.78 (0.01)
E. peplus	85.44 (8.96)	55.44 (5.33)	**0.01**	90.43 (0.05)
L. perenne	205.80 (18.15)	147.55 (7.69)	**0.01**	49.91 (0.08)
M. neglecta	111.40 (4.35)	95.03 (3.40)	**0.01**	75.31 (0.14)
P. lanceolata	204.87 (4.20)	143.02 (3.48)	**< 0.01**	62.22 (0.21)
P. tetraphyllum	135.95 (3.85)	104.12 (3.33)	**< 0.01**	60.64 (0.20)
R. acetosa	179.82 (9.14)	113.78 (1.90)	**< 0.01**	75.71 (0.11)
S. nigrum	143.44 (3.87)	105.12 (1.64)	**< 0.01**	54.83 (0.07)
T. repens	215.76 (4.43)	134.16 (3.96)	**< 0.01**	53.49 (0.13)

3.2 Relationships between Relative Growth Rate, Evapotranspiration and Leaf Relative Water Content

Evapotranspiration (ET) under well-watered (WW) conditions was strongly related to relative growth rate (RGR) (R^2=0.87; p=<0.001; Fig. 1). 'Fast' species with higher RGR had higher ET, whereas 'slow' species with lower RGR had lower ET. Leaf RWC under WD was also related to RGR (R^2=0.65; p=0.008; Fig. 1). Fast species were unable to maintain water status under WD.

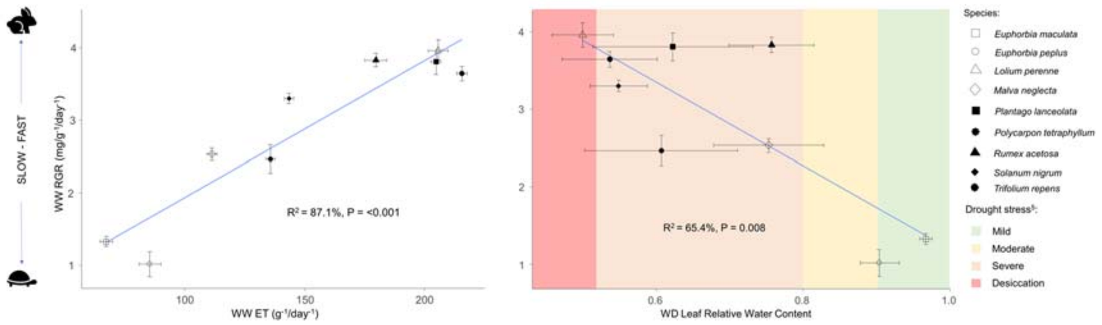

Figure 1: Relationships between plant relative growth rate (RGR) and evapotranspiration (ET) under well-watered (WW conditions), and leaf relative water content (RWC) under water deficit (WD). Colours indicate water status according to Hsiao (1973)'s drought stress categorisation scheme.

4 DISCUSSION

4.1 Water Use and Drought response of Green Roof Colonising Plants

Among the nine green roof colonising species there was a range of water use and drought response strategies. These strategies related to their relative growth rates and therefore their position along the 'fast-slow' continuum. 'Fast' species had greater ET under well-watered conditions and therefore could potentially increase rainfall retention on green roofs. 'Slow' species maintained higher leaf relative water contents under water-deficit and were therefore less sensitive to drought stress and could have greater survival on green roofs. However, a mixture of 'fast' and 'slow' species could provide stormwater mitigation and maintain vegetation cover on green roofs. The 'fast-slow' continuum is a valuable approach to select plants for green roofs and could be used to improve the functionality of designed plantings.

When compared to the highest transpiring native granite rocky outcrop species assessed by Farrell et al (2013), colonising species *L. perenne* transpired 19 % more water per day than *Isotoma axillaris*. This indicates that some green roof colonising species may contribute to stormwater retention. All species other than *E. maculata* and *M. neglecta* reduced their water use under water-deficit conditions. However, of the nine species, only *E. peplus* could balance improved stormwater mitigation with good survival (Farrell et al. 2013) by maintaining moderate water use under WW and maintaining high leaf water status under water-deficit. *E. maculata* also maintained high leaf water status under WD but achieved this through conservative water use under both scenarios.

The range of ‘fast-slow’ strategies exhibited by these nine species likely reflects changes in green roof plant communities over time, enabling them to co-exist. As evaporative demand increases, and water availability is reduced, ‘fast’ species would likely be replaced with ‘slow’ species that use less water and maintain water status. Diversity in fast-slow strategies could build resilience in vegetation communities and enhance their ecosystem function (Chesson 2000). Therefore, functional diversity in annual plants could optimise stormwater mitigation on green roofs (Van Mechelen et al. 2014).

5 CONCLUSION

‘Slow’ species in this experiment (*E. maculata* and *E. peplus*) both exhibited mild stress under WD. However, *E. peplus* maintained moderate water use under WW and down-regulated water use under WD to maintain water status; whereas *E. maculata* maintained low water use under both WW and WD to maintain water status. Overall, ‘fast’ species exhibited high water use under WW but also exhibited high stress under WD. Whereas, ‘slow’ species with low water use under WW exhibited low stress under WD. As diversity in fast-slow strategies could build resilience and enhance stormwater mitigation on green roofs, further study is required to determine rainfall retention by annual plants at the green roof level, and during different seasons.

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