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Research article

Performance evaluation of five Mediterranean species to optimize ecosystem services of green roofs under water-limited conditions

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A B S T R A C T

Rapid urban growth in Mediterranean cities has become a serious environmental concern. Due to this expansion, which covers adjacent horizontal ground, a critical deficit of green areas has been increasing. Moreover, irrigation is considered an important issue since water is one of the most limiting natural resources all over the world. The main objective of this study was to perform a long-term experiment to assess five Mediterranean species for extensive green roof implementation in Mediterranean-climate conditions. *Brachypodium phoenicoides*, *Crithmum maritimum*, *Limonium virgatum*, *Sedum sediforme* and *Sporobolus pungens* were grown in experimental modules under well-watered and water-limited conditions (irrigation at 50% and 25% ET_0, respectively). Plant growth and cover, relative appearance, color evolution and water use were determined periodically for two years. Shoot and root biomass were quantified at the end of the experimental period. The effects of the irrigation treatments and seasonal changes were assessed to identify the advantages and disadvantages of each species according to their environmental performance. All species survived and showed adequate esthetic performance and plant cover during the experiment. *S. sediforme* registered the lowest variation of relative appearance along the experiment, the highest biomass production and the lowest water consumption. Nevertheless, *B. phoenicoides* appeared to be an interesting alternative to *S. sediforme*, showing high esthetic performance and water consumption throughout the rainy season, suggesting a potential role of this species in stormwater regulation related with runoff reduction. *S. pungens* performed well in summer but presented poor esthetics during winter.

1. Introduction

The rapid increase of urban areas is considered one of the drivers of global climate change, with an important negative environmental impact. A lack of green infrastructures and an increase in impervious surfaces usually characterize urban areas, and as a consequence, cities are affected by the heat island effect, environmental pollution and altered hydrology that adversely affect quality of life and human health (Carter and Rasmussen, 2005; Jarrett et al., 2007). Green infrastructures can attenuate those negative impacts since they are able to provide a wide range of supporting, cultural and ecosystem-regulating services (Bendell et al., 2010; Hien et al., 2003; Peng and Jim, 2013). Among the services, the implementation of extensive green roofs has been generally recognized as a practice that provides several ecosystem services in urban areas, including atmospheric and acoustic pollution reduction (Veisten et al., 2012; Yang et al., 2008), stormwater management (Fioretti et al., 2010; Mentens et al., 2006; Palla et al., 2008; Schroll et al., 2011; Wolf and Lundholm, 2008), thermal regulation (Butler and Orians, 2011; Chen et al., 2009; Getter et al., 2011; Hien et al., 2003; Lundholm et al., 2010; Peng and Jim, 2013; Santamouris et al., 2007; Sharma et al., 2016) carbon sequestration (Getter et al., 2009; Whittinghill et al., 2014), biodiversity improvement (Kadas, 2006; Dvorak and Volder, 2013; Oberndorfer et al., 2007) (Clemants et al., 2006; Dvorak and Volder, 2013; Oberndorfer et al., 2007) and esthetic and social benefits (Fernandez-Cañero et al., 2013; Jungels et al., 2013).

Extensive green roof infrastructure was quickly embraced in European and North American cities during the second half of the 20th Century due to the synergy between the abovementioned ecosystem and social services (Oberndorfer et al., 2007). However, in most semi-arid and Mediterranean-climate areas long summers

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and water scarcity limit green roofs adoption. In the sense used here, the Mediterranean climate is characterized by hot, dry summers and cool winters, a combination that limits perennial plant performance of C4 and CAM drought-adapted species due to relatively low winter temperatures (Toscano et al., 2015), and of C3 species due to summer drought (Bevilacqua et al., 2015; Durhman et al., 2007; Price, 2013). Moreover, plant selection is also constrained by the invasive ability of many ornamental and exotic species (Gritti et al., 2006), suggesting the importance of evaluating the performance of native species and focus in plant selection, since plant species largely determine the functionality and efficiency of extensive green roofs (Lundholm et al., 2010; Vijayaraghavan, 2016).

In a global scenario in which water resources are scarce, sustainable water management appears to be one of the most challenging issues in the near future. Direct human consumption, industry and irrigation of both agricultural fields and urban green areas compete for water resources, significantly limiting water availability for urban green areas, since this is usually considered a low-priority use. This situation is even more dramatic in semi-arid and Mediterranean-climate areas (Van Mechelen et al., 2015), suggesting the relevance of providing accurate data regarding the water requirements of different species to be used in urban green areas (García-Navarro et al., 2004). *Sedum* species are commonly used in green roof implementation due to the drought tolerance and high ground cover ability under water-limited conditions conferred by their leaf morphology, photosynthetic metabolism and high water-use efficiency (Blanusa et al., 2013; Monterusso et al., 2005).

In addition to water limitation during summer, oversaturation of urban drainage systems during the rainy season has been identified as a problem in many Mediterranean cities. The reduction and delay of runoff are considered potential green roof services (Fioretti et al., 2010; Mentens et al., 2006; Palla et al., 2008; Jefferies and Doménech, 2015). However, that service would be more efficiently performed if species with high water consumption abilities were used in green roof implementation suggesting a trade-off among vegetation functional goals (Benvenuti and Bacci, 2010; Blanusa et al., 2013; MacIvor and Lundholm, 2011; MacIvor et al., 2013, 2011; Eksi et al., 2017; Schweitzer and Erell, 2014), since those species that are able to consume large amounts of water usually show low performance under water-limited conditions (Durhman et al., 2007). Nevertheless, some herbs, grasses and geophytes, usually high water consumers, have reported high survival rates and optimal recovery after a drought period. (Van Mechelen et al., 2015; Szota et al., 2017). Those species have shown a number of responses to water stress such as root growth increase, leaf size reduction, high stomatal response and isohydric behavior (Farrell et al., 2013; MacIvor et al., 2013; MacIvor and Lundholm, 2011; Nagase and Dunnett, 2010). However, in addition to plant species traits, the irrigation regime and the substrate characteristics would also determine to a great extent the ability of a green roof system to reduce stormwater runoff and delay peak flows (Fioretti et al., 2010; Mentens et al., 2006; Palla et al., 2008; Wolf and Lundholm, 2008).

The esthetic value is also recognized as an ecosystem benefit provided by green roofs (Bendell et al., 2010; Fernandez-Cañero et al., 2013), though it is rarely emphasized, and very little information is known about this benefit. Several studies have suggested that future research on plant selection should consider and better quantify plant architecture and form, flowering length, color and greening variation during the year and biomass production, and how water supply and other management techniques affect vegetation and green roof performance (Benvenuti and Bacci, 2010; Dunnett et al., 2008; Durhman et al., 2007; Emilsson, 2008; Fernandez-Cañero et al., 2013; Lundholm et al., 2010; MacIvor et al., 2013; Monterusso et al., 2005; Nagase and Dunnett, 2010).

In this context, identifying species able to withstand drought with an optimal appearance and growth but also capable of achieving high water consumption during the rainy season in order to enhance runoff reduction would greatly improve green roof functionality in Mediterranean-climate areas. The present experimental and long-term study aims to study the performance of 5 Mediterranean species in experimental extensive green roofs under two different water regimes. The following specific objectives are addressed: i) to study the ability of 5 Mediterranean species to cope with water limited condition by determining plant cover, biomass accumulation, relative appearance and coloration; and ii) to determine the water use of those species in order to evaluate their potential uses in stormwater management and estimate their water-use efficiency under extensive green roof conditions.

2. Material and methods

2.1. Plant material and experimental design

The experiment was performed at the University of the Balearic Islands, Spain, (West Mediterranean Basin, 39°38′ N, 2°38′ E) at 80 m a.s.l., where the mean annual rainfall is 427 mm and the annual mean temperature is 17 °C (AEMET, 2011).

Five Mediterranean species, *Asteriscus maritimus* L. *Less., Brachypodium phenicoides (L.) Roem. Et schultes, Crithmum maritmun* L., *Limonium virgatum (Willd.) Fourr, Sedum sediforme (jacq.) Pau and Sporobolus pungens (schreber) kunth* (Table 1) were considered in this study. These species were considered potentially suitable for extensive green roof conditions because they grow in natural habitats characterized by shallow soils with low organic matter content, high solar radiation and extreme temperature, conditions that can be similar to those in extensive green roofs. Moreover, perenniality, low biomass production, high germination rates and potential esthetic value were also considered as criteria for selection.

Experimental modules of 0.75 m × 0.75 m and 0.15 m depth were installed one meter above the soil. The modules were filled with commercial green roof layers from the top to the bottom as follows: 1) 0.12 m of substrate composed of a recycled product based on specially processed clay tiles with 10.6% organic material. This substrate is considered suitable for extensive green roofs due to its stable structure, high permeability and aeration capacity (Barco, 2008). The bulk density is 1120 g/l (ZinCo, ZinCo_FT Zincoterra Floral, SL, Spain) (Zin Co, 2012c). Soil water content at field capacity (27.9%) was determined by gravimetric methods (watering to saturation and allowing 12 h of drainage and 48 h of drying at 105 °C). 2) a filter sheet of Geotextile thermally strengthened polypropylene (ZinCo, Filter system SF; ZinCo SL, Spain) (Zin Co, 2012b). 3) a drain system of thermoformed recycled polyolefin (Floradrain FD 25-E, ZinCo, SL, Spain) (Zin Co, 2012a) with a water storage capacity of 3 mm. 4) a protection mat of recycled synthetic fibers made of polyester (ZinCo, Protection mat SSM 45; ZinCo SL, Spain) (Zin Co, 2012d) with a water storage capacity of 5 mm.

Seeds were germinated in seed benches with horticultural substrate (Prohumin Substrate Klasmann-Deilmann) between October and November 2012 under greenhouse conditions. Seedlings were grown under those conditions until February 2013, when they were placed outdoors to facilitate plant acclimation. In mid-March, after 45 days outdoors, 9 plants of the same species were planted in each module (16 plants per m^2).

To ensure plant establishment, all modules were kept at field capacity from transplantation to June 2013, when two water treatments were imposed. The amount of water supplied for each