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Evaluating the growth of several Mediterranean endemic species in artificial substrates: Are these species suitable for their future use in green roofs?

S. Ondoño [a,*], J.J. Martínez-Sánchez [b], J.L. Moreno [a]

[a] Grupo de Enzimología y Biorremediación de Suelos y Residuos Orgánicos, Centro de Edafología y Biología Aplicada del Segura (CEBAS-CSIC), Campus Universitario de Espinardo, Aptdo. de correos 164, Espinardo, 30100 Murcia, Spain

[b] Departamento de Producción Vegetal, Universidad Politécnica de Cartagena (UPCT), Paseo Alfonso XIII, 48, CP 30203 Cartagena, Murcia, Spain

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ABSTRACT

The study of the growth of several Mediterranean endemic plant species in new artificial substrates is becoming necessary for seeking alternatives in green roof design in Mediterranean regions. In this regard, we evaluated the growth of six native species on three different artificial substrates. These species were *Silene vulgaris, Silene secundiflora, Crithmum maritimum, Lagurus ovatus, Asteriscus maritimus*, and *Lotus creticus*. A mixture of a green compost with a clay–loam soil (C + Soil), the same compost mixed with expanded clay (C + Clay), and the compost mixed with crushed bricks (C + Bricks) – all in 1:4 volumetric proportions – were the assayed substrates. Physichochemical and biochemical properties were studied in each mixture at the beginning and end of a three-month assay. Besides, the germination and growth of all plant species in each substrate type were evaluated. The mixtures C + Clay and C + Bricks showed greater porosity than C + Soil, leading to a high root: shoot biomass ratio in all species tested. Conversely, the mixture C + Soil possessed better biochemical properties (higher humic substances content and enzyme activity), but they decreased with experimental time. Contrarily, the humic substances and the dehydrogenase activity increased in the most porous mixtures. Regarding plant behaviour, *S. vulgaris* and *L. ovatus* showed greater germination and growth than the other species, especially above C + Clay and C + Bricks mixtures. Accordingly, we strongly recommend the use of lightweight and highly porous substrates as the basis for the growing of Mediterranean native herbaceous species, since they specially enhance their root development. The combined use of perennials and annuals species in that kind of substrates could provide a permanent plant cover in a green roof scenario.

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1. Introduction

Extensive green roofs are generally substrate-based systems with a vegetated layer typically compound of *Sedum* spp., offering between 2.5 and 5 cm thickness, according to the FLL Guidelines (2002). *Sedum* mat systems only comprise stonecrop species and are installed to obtain quick green cover. The substrate used in this kind of green cover is mainly composed of a sponge membrane with a substrate base (Molineux et al., 2009). These species are generally considered the most appropriate plants to apply to extensive green roofs, due to their shallow root systems, Crassulacean acid metabolism (CAM), and their efficient water use, as well as their tolerance to extreme conditions of heat and drought (Benvenuti and Bacci, 2010; Durhman et al., 2007). Although native plants have largely been ignored in the design of green spaces, the use of autochthonous species of wild flora in xerogardening, landscaping and revegetation is of increasing

Abbreviations: A. Maritimus, Asteriscus maritimus; AB, aboveground biomass; ADP, adenosine di-phosphate; APA, alkaline phosphatase enzyme activity; ATP, adenosine tri-phosphate; β-GLA, β-glucosidase enzyme activity; CAM, crassulacean acid metabolism; *C. maritimum, Crithmum maritimum*; CP, carbon content in plant tissues; C + Bricks, green compost mixed with crushed bricks (1:4 volumetric proportions); C + Clay, green compost mixed with expanded clay (1:4 volumetric proportions); C + Soil, green compost mixed with a clay–loam soil (1:4 volumetric proportions); DHA, dehydrogenase enzyme activity; FAO–ISRIC and ISSS, Agriculture Organization Food – World Soil Information and International Space Station; ICP-AES, inductively-coupled plasma-atomic emission spectroscopy; INT, *p*-iodonitrotetrazolium chloride; INTF, *p*-iodonitrotetrazolium formazan; *L. ovatus, Lagurus ovatus*; *L. creticus, Lotus creticus*; MUB, universal modified buffer; NP, N content in plant tissues; OM, organic matter; PCA, principal component analysis; PR, substrate porosity; RB, root biomass; RH, relative humidity; RL, total root length; R:S, root/substrate volume ratio; *S. secundiflora, Silene secundiflora*; *S. vulgaris, Silene vulgaris*; TC, total carbon; TN, total nitrogen; TOC, total organic carbon; T_{50}, number of days it takes to germinate 50% of seeds; URA, urease enzyme activity; UV–VIS, ultraviolet–visible spectrophotometer; WHC, water holding capacity.

* Corresponding author. Tel.: +34 968396259.
E-mail address: sotovar@cebas.csic.es (S. Ondoño).

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interest because of their capacity to adapt to adverse environmental conditions (Martínez-Sánchez et al., 2003Martínez-Sánchez et al., 2003 Franco et al., 2001; Cabot and Travesa, 2000; Sánchez-Blanco et al., 1998). In this sense, the use of native forbs and grasses in green roof designing is increasing nowadays in Mediterranean countries (Van Mechelen et al., 2014; Papafotiou et al., 2013; Kotsiris et al., 2012; Nektarios et al., 2011; Benvenuti and Bacci, 2010). Therefore, the substrate composition and depth has changed. Deeper substrates are more suitable for native species due to the highly developed root system that they usually possess. Also, deep substrates are more suitable than shallower ones for goals like improving storm-water management in big cities (Nagase and Dunnet, 2011; Fioretti et al., 2010), and achieving higher thermal insulation and energy savings in buildings (Jaffal et al., 2012; Jim and Tsang, 2011). Hence, the substrate depth in these new systems is about 10–20 cm, and is usually made up of a mixture of an organic component, normally compost, which usually represents between 0 and 20% of the total volume of the mixture, and an inorganic material, such as crushed bricks, expanded clay, zeolite, pumice or sand, which is the major component of the mixture. The use of crushed bricks and light expanded clay granules, both mixed with compost, are common materials used as green roof substrates (Oberndorfer et al., 2007). These mixtures are increasing nowadays due to their reduced environmental impact with respect to the extraction and production of new materials and for their low price (Emilsson, 2008). Therefore, the substrate must be formulated to meet the physical, chemical and biological needs of plants (Beattie and Berghage, 2004). Hence, all of the physicochemical, biochemical and microbiological properties of substrates should be studied to obtain further information about the future green roof behaviour in a real situation (Ondoño et al., 2014). In this sense, each constituent of green-roof substrates has an important role. On the one hand, the organic part contributes to increase the water retention capacity in the mixture, improving the substrate structure. Besides, its mineralization by the microorganisms provides a continuous flux of nutrient to the plants (Havlin et al., 2005). On the other hand, the inorganic component primarily acts as a physical support for plants, which should have high porosity, allowing good drainage conditions.

Recently, the commercial utilization of Mediterranean native species has been of great international interest. The Mediterranean region constitutes an important source of endemic plants with high potential for use as ornamental plants, because of its geomorphological and climatic characteristics. These species must overcome the typical stresses of Mediterranean climate zones, especially the long and intense summer drought (Terradas and Savé, 1992); hence, they are good candidates for replacing *Sedum* spp. in extensive green roofs under semi-arid climates, a species which presents some potential problems associated with monocultures of stonecrops (Rowe et al., 2006). Most Mediterranean perennial species clearly optimize carbon assimilation and minimize water loss with the tight regulation of their stomatal conductance (Savé et al., 1999); the root part also plays a role in water use optimization in a variable environment (Alscher and Cumming, 1990). These species are typically used in green roof systems primarily for goals like erosion prevention (Clary et al., 2004); annual species are also often used because they provide a quick ground cover (Brown and Rice, 2000). On the other hand, the use of annuals is increasing nowadays, due to fact that they have rapid growth and blooming, and they may be attractive in the spring and early summer for pollinators owing to their colorful flowers (Filippi, 2008). Besides, seed production is added to the seed bank; hence, forming a buffer against eventual gap formation while other herbaceous plants die off. This property is a natural survival strategy of annuals to thrive in regions with very unpredictable weather conditions (Madon and Médail, 1997). Therefore, the incorporation of annuals in green roof designing, alongside evergreen species, can improve green roof performance and should be considered (Van Mechelen et al., 2014).

We aim to introduce a variety of different Mediterranean species, both annual and evergreen species, into a typical extensive substrate-base of a green roof. In this work, we studied the germination capacity and subsequent development of five Mediterranean species on three different artificial substrates. Therefore, we hypothesized that: (i) both the perennial forbs and the annual grasses can thrive in these artificial substrates under controlled temperature and moisture conditions; (ii) the physico-chemical substrate properties are of paramount importance in plant development, and will be the deciding factor for selecting an appropriate substrate for its use as a green roof basis, and (iii) the compost-inorganic material mixtures will be better than the compost-soil substrate for the sustainability of these endemic plant species.

2. Materials and methods

2.1. Substrates used and plant species tested

We used three different substrates. All of them were composed of a compost mixed with one of three different materials: crushed bricks (C + Bricks), expanded clay (C + Clay) or a clay–loam soil (C + Soil), all in a 1:4 volumetric ratio. The compost was made from sheep and goat manure mixed with green wastes (plant prunings and debris), supplied by the company Abonos Orgánicos Pedrín (Murcia, Spain). The soil is classified as a *Haplic Calcisol* (FAO–ISRIC and ISSS, 1998). This soil was sampled in Santomera (Murcia, Spain), from a fallow land, and was then sieved to 2 mm. The crushed bricks were from construction industry residues (4–12 mm of diameter) supplied by a local factory (Triturados

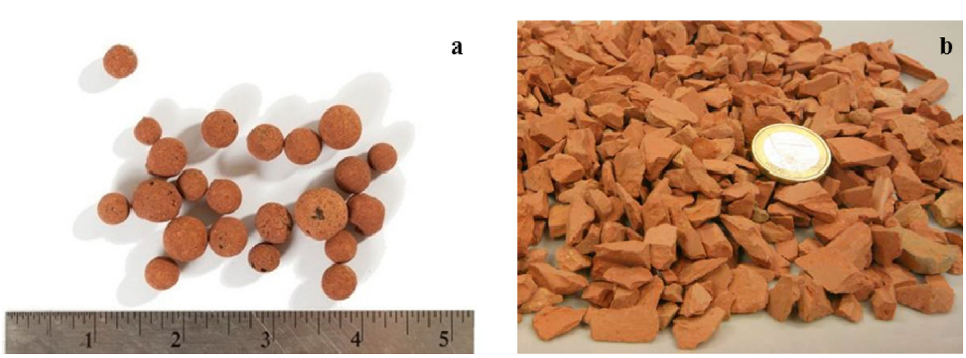

Fig. 1. Inorganic materials used. (a) Expanded clay by thermal action (4–12 mm of diameter), and (b) crushed cooked bricks (8–16 mm of diameter).

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