Composition and depth of Extensive Green Roof substrate affect the growth of two Mediterranean plant species under different irrigation conditions

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RESUMEN

Recently, the design of new substrates capable of sustain an adequate plant development in Green Roof systems under Mediterranean climatic conditions is a challenge due to the unfavorable hot and dry conditions. The use of suitable light-weight substrates which can promote an adequate plant growth and maintenance over time is an important achievement as well as the plant species selection. The most commonly used plants in Green Roof systems are the Crassulacean since they are perfectly fitted to drought conditions. In this sense, the use of herbaceous and shrub endemic Mediterranean species could provide an added value in green roof designing under semi-arid conditions. Therefore, we aim to evaluate the growth of two endemic species (*Silene vulgaris* (Moench) Garcke and *Lagurus ovatus* L.) in two different substrate types with two different depths. To be precise, one substrate was made of a mixture of compost and crushed bricks (CB) (1:4; v:v), and the other one was made of compost-soil-bricks (CSB) (1:1:3; v:v:v). Physichochemical, biochemical as well as microbiological properties were evaluated in both substrates in order to study its suitability as plant growth basis. The results showed that both substrates showed adequate physichochemical properties to promote plant growth, but the CSB mixture presented better biochemical and microbiological properties than CB, allowing a suitable environment for microbial and plant development. Furthermore, both plant species had higher coverage and grater SPAD values in CSB than in CB mixture, and this growing was higher above deeper substrates (10 cm) than on 5 cm-substrate depth, being this parameter more significant for plant development than substrate composition.

Keywords: Green roof; artificial substrates; irrigation; plant coverage; SPAD.

1. Introduction

Extensive green roofs are light-weight systems with minimal substrate depth and minimal maintenance requirements [1]. Green roof substrates should be light-weight, chemically inert, physically stable, and they should retain adequate amounts of water and minerals for sufficient plant growth [2]. The majority of green roof substrates tend to be dominated by mineral-based components with an organic matter that varies according to the green roof type [1]. Typically, its composition is made of 80% to 100% of mineral and 0% to 20% of organic matter, which contribute to water- and nutrient-holding capacities [3].

Recently, the design of new substrates capable of sustain an adequate plant development under Mediterranean climatic conditions is a challenge due to the unfavorable hot and dry semi-arid conditions. Therefore, the use of suitable light-weight substrates which can promote an adequate plant growth and maintenance over time is an important achievement in the Mediterranean area as well as plant species selection. The use of herbaceous and shrub endemic plants could provide an added value in green roof designing, taking into account that endemic species are also well adapted to these conditions.

On the other hand, irrigation is needed in extensive green roofs under Mediterranean climate, but the amount and the frequency is related to plant species and substrate type and depth. A high substrate depth would be desirable for water retention in a dry roof management scenario, but on the other hand, this would pose the risk of excessive weight after heavy downpours [4]. Therefore, we have to find a suitable substrate-depth to promote plant growth and, at the same time, to avoid an excessive substrate bulk. For this proposal, we have tested two different materials in two different depths in order to find an appropriate substrate for being used under Mediterranean climatic conditions. To be precise, one substrate was made of a mixture of compost and crushed bricks (CB) in 1:4 volumetric proportions, and the other one was made of compost-soil-bricks (CSB) (1:1:3; v:v:v). Both of them were prepared in two depths: 5 and 10 cm. We conducted an assay at field level to evaluate the effect of substrate composition and depth into two Mediterranean plant species under irrigated (40% of ET_0 values) and non-irrigated regime. In this sense, we postulated that in an extensive green-roof experiment: i) the mixture CSB may have better biochemical and microbiological properties to enhance plant growth than CB, ii) both plant species will have better development in deeper substrates than in 5 cm-substrate depth, iii) 40% of ET_0 irrigation conditions can allow plant growth, but plants could not develop properly under non-irrigated conditions.

2. Materials and Methods

2.1. Substrates, plant species and irrigation conditions

We tested two different substrates in two depths: 5 and 10 cm. These substrates are compost mixed with crushed bricks (CB), in a 1:4 volumetric ratio, and compost mixed with soil and crushed bricks (CSB) in 1:1:3 (v:v:v). Two plant species were tested in these substrates; *Silene vulgaris (Moench) Garcke,* and *Lagurus ovatus L.*

Seeds of both plant species were sown in each substrate using a planting framework (5x5 cm). Each type of substrate was prepared in triplicate for each species and for each substrate depth. For this proposal, we designed six stainless “cultivation tables” with dimensions of 3x1.5 m everyone. Each cultivation table was composed of eight units of planting, measuring 0.75 x 0.75 x 0.20 m, so there were 48 different units. Three of those cultivation tables were assigned to non-irrigated conditions and the other three were subjected to irrigation at 40% of the potential evapotranspiration (ET_0) registered values. The essay was conducted in an experimental farm located in Santomera (Murcia) from November-12 to July-2013.

2.2. Substrate measurements

Physichochemical properties (water holding capacity, wilting point, bulk density, porosity, organic matter content, TC, and TN) were measured in each substrate. Besides, analyses of principal biochemical and microbiological properties were carried out (enzyme activities related to C, N, and P cycles) in order to study each substrate from an agronomic point of view initially and at the end of the trial.

2.3. Plant measurements

Plant coverage was measured by digital image analysis using a digital camera and the RSI ENVI 4.0 software to process the images. SPAD (soil-plant analysis development) index was measured in both plant species to estimate the chlorophyll state during the growing season (April-May 2013). Finally, all plants were cut and dried to estimate the aboveground-biomass dry weight of each species as well as the water-use efficiency (WUE) by each unit. Plant samples were pulverized in a grinder, and then the nutrient content was also measured in plant tissues.

2.4. Statistical analysis

All the results are reported as means of triplicate analyses (n=3). The ANOVA for repeated measures was carried out in order to determine the statistical significance of the differences in the values of each variable between the sampling times (intra-subject). Thereafter, Tukey´s *post-hoc* test was performed to determine the HSD (honestly significant differences) of the mean values of each variable between substrate type and depth (inter-subjects).

3. Results and Discussion

3.1. Substrate measurements

CB had higher porosity and less density than CSB, which are both good properties for green roof substrate designing [5-8], while CSB presented greater organic matter content as well as higher water-holding capacity (Table 1) owing to organic matter can act as an adhesive between soil particles, resulting in improved moisture-holding capabilities [9]. All these properties are of paramount importance in plant growth.

An enhancement of TC, TOC, and TN was observed in all substrates for both plant species regarding to the start of the trial, and between irrigated and non-irrigated conditions, especially in CSB substrates, being this enhancement more significant with substrate type than with substrate depth. The amount of humic substances also increased in CSB, and especially to the depth of 10 cm, whereas in CB5 the amount of fulvic acids significantly ($p<0.05$) decreased with time. These C and N trends can affect the enzyme activity in each substrate. β-GLA and URA are extracellular hydrolase enzymes which are involved in C and N cycles, respectively, and are related with the organic matter decomposition pathways. Both activities increased with the experimental time, and were promoted in CSB mixture as well as in deeper substrates.

3.2. Plant measurements

Plant coverage was significantly higher ($p<0.05$) in deeper substrates, above all in CSB mixture for both species, being this coverage significantly higher for *L. ovatus* than for *S. vulgaris* (Fig. 1).

Chlorophyll content (SPAD index) was greater in *S. vulgaris* than in *L. ovatus* for all substrates tested (Fig. 2) due to the first one is a perennial specie which remains green throughout the year, and the other one is an annual specie which withers to the arrival of summer. Both species showed higher SPAD values in deeper substrates than in 5 cm-substrate depth. Other authors [10] also obtained the same results; significantly higher SPAD values in deeper profiles.

The aboveground biomass measured in each unit also followed this tendency; the substrate depth is more influential than the substrate type in plant growth, being the most important indicator of plant successful in green roofs [5]. WUE was also significantly higher in deeper substrates than in shallower ones (Table 2), being higher in CSB10 substrate than in CB10, and was significantly greater for *L. ovatus* than for *S. vulgaris* for every substrate.

In general, some authors [11, 12] have found the substrate depth as a most influential factor on plant physiology than the substrate type when grown on green roof systems.

4. Conclusions

It has been shown that the soil made substrate (CSB) better promote the enzymatic activity than CB mixture, being these effects more pronounced with the substrate depth. In CSB mixtures there were a great enzymatic activity related to C, and N cycles, which increased throughout the experiment. These characteristics lead to an adequate plant development in these substrates for both Mediterranean species.

Regarding to plant growth and production we assess that the substrate depth is a more influential factor than the substrate type, although CSB10 mixture is the most suitable combination from every point of view. Both plant species had an appropriate development under irrigation conditions (40% of ET_0), but none could grow without water supplies.

5. Acknowledgments

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6. References

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Tables and Figures

	pH	EC µS cm^{-1}	Organic Matter %	WHC %	Wilting Point %	Bulk density g cm^{-3}	Particle density g cm^{-3}	Porosity %	Weigth Kg m^{2} (dry soil)
Compost-bricks (1:4)	8.08 (0.12)	262 (0.22)	3.458 (0.205)	32.84 (1.35)	18.40	0.980 (0.015)	2.587 (0.004)	78.349 (0.031)	98 (10 cm) 49 (5 cm)
Compost-soil-bricks (1:1:3)	8.48 (0.04)	123 (0.45)	7.565 (0.053)	35.50 (1.51)	18.70	1.050 (0.010)	2.515 (0.001)	58.449 (0.015)	105 (10 cm) 52.50 (5 cm)

Table 1. *Main physichochemical characteristics of two substrates tested. Values in brackets represent standard deviations.*

	CB5-L	CB10-L	CSB5-L	CSB10-L	CB5-S	CB10-S	CSB5-S	CSB10-S
Bloom index	1034 c	1174.67 d	362 b	1264.67 d	98 a	104 a	94.67 a	252 b
WUE	0.25 c	1.15 f	0.17 bc	1.94 g	0.09 ab	0.50 d	0.05 a	0.80 e
TC	39.18ab	38.75 ab	40.35 bc	37.50 a	42 c	42.67 c	40.79 bc	40.13abc
TN	0.61 a	0.67 a	0.73 b	0.57 a	1.31 c	1.34 c	1.38 c	1.36 c
Ca	0.30 bc	0.33 cd	0.25 ab	0.55 f	0.39 d	0.22 a	0.35 cd	0.45 e
K	3.33 d	3.37 d	2.15 ab	3.33 d	2.34 bc	2.29 bc	1.82 a	2.68 c
Mg	0.14 a	0.25 c	0.11 a	0.19 b	0.33 e	0.30 d	0.38 f	0.36 ef
Na	1.07 e	0.76 d	0.71 d	1.06 e	0.33 b	0.15 a	0.28 b	0.51 c
P	0.80 d	0.68 c	0.74 cd	0.75 cd	0.41 ab	0.39 ab	0.45 b	0.32 a
S	0.41 d	0.61 e	0.55 e	0.74 f	0.20 b	0.13 a	0.31 c	0.32 c

Table 2. *Plant characteristics and nutrient concentrations in plant tissues measured for each specie grown in each substrate after harvest. For each variable, same letters means that there are not significant statistical differences (p<0.05) between substrates and between values according to Tukey-b test.*

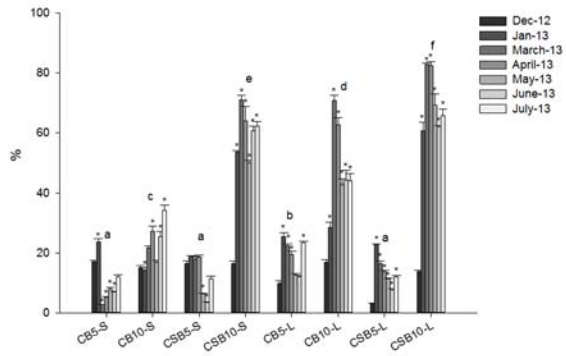

Figure 1. *Plant coverage measured by digital image analysis. Results are expressed in percentaje of the total sampling area for each sampling time. The asterisk denotes significant differences at p<0.05 level regarding the first sampling time and substrates followed by the same letter do not present significant differences (p<0,05) between them according to Tukey-b test. Error bars represent standard error.*

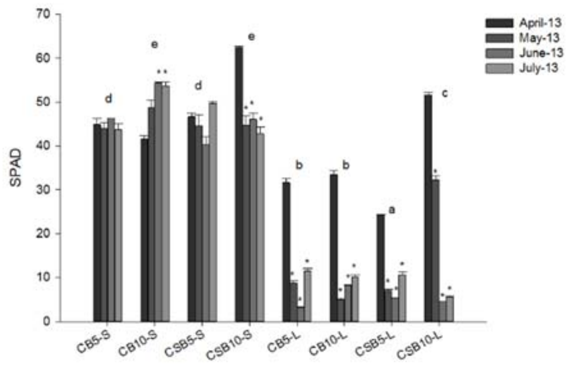

Figure 2. *Plant chlorophyll content (SPAD) measured in irrigated units. The asterisk denotes significant differences at p<0.05 level regarding the first sampling time and substrates followed by the same letter do not present significant differences between them according to Tukey-b test. Error bars represent standard error.*