INNOVATIVE GREEN ROOFS FOR SOUTHERN EUROPE: BIOCRUSTS AND NATIVE SPECIES WITH LOW WATER USE

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Abstract *In regions of Europe with dry hot summers, the cost of watering green roofs can outweigh the benefits. A low-water use solution is under development in the frame of the project NativeScapeGR, by associating native plant species and biocrusts to build a new type of green roof. The use of these species aims at creating valued and valuable landscape urban areas, lowering water requirements to a minimum level, without compromising aesthetic value, enhancing biodiversity and sustainability, whilst facilitating a tool for climate change adaptation.*

The main objectives of the project are: 1) to study green roofs as alternative urban landscapes, regarding low water requirements and the use of native species and biocrusts, in order to: i) save water, ii) take advantage of environmental adaptations of native species, namely to drought conditions, to create landscape areas that maintain ecological, functional, aesthetic and recreational value, iii) avoid the introduction of invasive species and iv) promote biodiversity and wildlife refuges in urban areas; 2) to quantify the water requirements of landscape species/areas by: i) quantifying the water requirements of a set of chosen native species using gravimetric measurements of potted plants, in relation with irrigation levels and ornamental value and ii) quantifying the water requirements of green roofs with native plants, by the use of soil water balance; 3) to test the possibility of using biocrusts in green roofs based on the use of mosses, without additional water and comparing the performance of these organisms with the average/expected advantages of a green roof, namely the capacity to retain water and reduce roof temperatures; 4) to test the hydrological performance of the green roofs, namely the mitigation of stormwater runoff generation. Experimental work is underway consisting in the accurate monitoring and observation of twelve different treatments in large trays simulating green roofs, characterized by different levels of irrigation, different plants and mosses and different substrates.

1. INTRODUCTION

Urban landscapes frequently have gardens with exotic plant species. These species can become invasive and have negative impacts, such as the extinction of and competition with native species [1],[2], hybridization [3] and perturbation of hydrological cycles [4],[5]. Fauna can also be disturbed negatively by the change of natural habitats. Invasive species can find a foothold in non-previously occupied habitats, establish a population and spread autonomously, presenting a conservation threat by modifying the existing ecosystem [6]. The presence of exotic species in urban areas is quite common in Mediterranean climate areas.

An alternative to exotic plants is the use of native plants, which are better adapted to the Mediterranean climate than most introduced plants, also offering benefits to local wildlife, such as insects and birds [7]. Relocating native wild plants in the urban environment contributes to species conservation and is a way of increasing biodiversity.

Exotic species coming from more humid climates require additional amounts of irrigation water to thrive in Mediterranean dryer conditions. This has led to landscapes with high water requirements, frequently turf grass based. It is known that the fraction of landscape water requirements in relation to reference evapotranspiration increases with the fraction of turf grass in the landscape [8]. The water consumption for lawns in a summer day can be as high as 6 mm d^{-1}, less when the lawn is shadowed by trees and higher when lawns are fully exposed to radiation and to local advection effects [9],[10],[11]. Irrigation in these cases can be very expensive and environmentally unsustainable.

Native Mediterranean plants are adapted to long, dry summers, enduring dryness conditions. Therefore, low water requirements are one of the interesting features these plants have, allowing to have a landscape with ornamental value while saving water. This reduces the pressure on groundwater and the pumping costs and enhances the sustainability of the process. Furthermore, a non-irrigated landscape in such conditions would represent a major advantage. In extreme cases, where irrigation water is not available, the dry and hot summer conditions have some similarity with arid climates, which have less than 200 mm of precipitation. Deserts are covered with biocrusts (Biological Soil Crusts), which are consorcia of cyanobacteria, fungi, bryophytes and lichens that can grow in extreme low water conditions due to their poikilohydric traits. They are able to photosynthesize when water is available but, under dryness they resume photosynthesis and shut down their metabolism. They can remain under these conditions for long periods of time ranging from months to years. When water becomes available, they resume photosynthesis. The use of these biocrust species in non-irrigated areas represents an innovative possibility for urban landscape under Mediterranean climate conditions.

The approach presented in this work combines the use of native plant species and selected species from biocrusts (moss dominated) with an alternative urban landscape, the green roofs. Green roofs are enhancers of the urban vegetated footprint, with numerous increased environmental and well-being benefits. These benefits include storm-water management, building temperature control, increased longevity of roofing membranes, mitigation of the urban heat island effect, potential carbon sequestration, potential noise mitigation and make available aesthetically pleasant environments for people to use, with increased biodiversity.

Green roofs have thus multiple environmental benefits but in Mediterranean areas they are not common due to high inputs requirements (water) and maintenance costs.

The hypothesis under study is then that these newly named 'Biocrust Roofs', may be applied in Mediterranean areas without any additional water requirements, or with low irrigation amounts when biocrust species are combined with native plants.

2. THE NATIVESCAPEGR PROJECT

The NativeScapeGR project is currently being developed at the University of Lisbon, coordinated by Instituto Superior de Agronomia (ISA) and with the collaboration of a team from the Faculty of Sciences, two private enterprises (Neoturf and Sigmetum) and the Mediterranean Garden Society.

The main idea behind the project focuses on using native plant species to create new landscape urban areas in roofs, lowering water requirement to a minimum level without compromising aesthetical value but enhancing biodiversity and sustainability, whilst facilitating a tool for climate change adaptation.

The main objectives of the project are:

1) to study green roofs as alternative urban landscapes, regarding low water requirements and the use of native species in order to save water, take advantage of environmental adaptations of native species, namely to dryness conditions, to create landscape areas that maintain ecological, functional, aesthetic and recreation value, to avoid the introduction of invasive species and to promote biodiversity and wildlife refuges in urban areas;
2) to quantify the water requirements of landscape species/areas by: i) quantifying the water requirements of a set of chosen native species using gravimetric measurements of potted plants, in relation with irrigation levels and ornamental value, ii) and quantifying the water requirements of green roofs with native plants and biocrust mosses through the soil water balance;
3) to simulate the water requirements of green roofs regarding irrigation scheduling by using a model formerly adapted to agricultural applications, thus extending it to landscape areas;
4) to test the possibility of using biocrusts in green roofs based on the use of mosses without additional water and comparing the performance of these organisms with the average/expected advantages of a green roof, namely the capacity to retain water and reduce roof temperatures;
5) to test the hydrological performance of the green roofs and the capacity to replace ecosystem functions.

Figure 1 presents a schematic description of the project, showing briefly how measurement and modelling of plant water requirements is combined with aesthetic evaluation to test this new approach to green roofs.

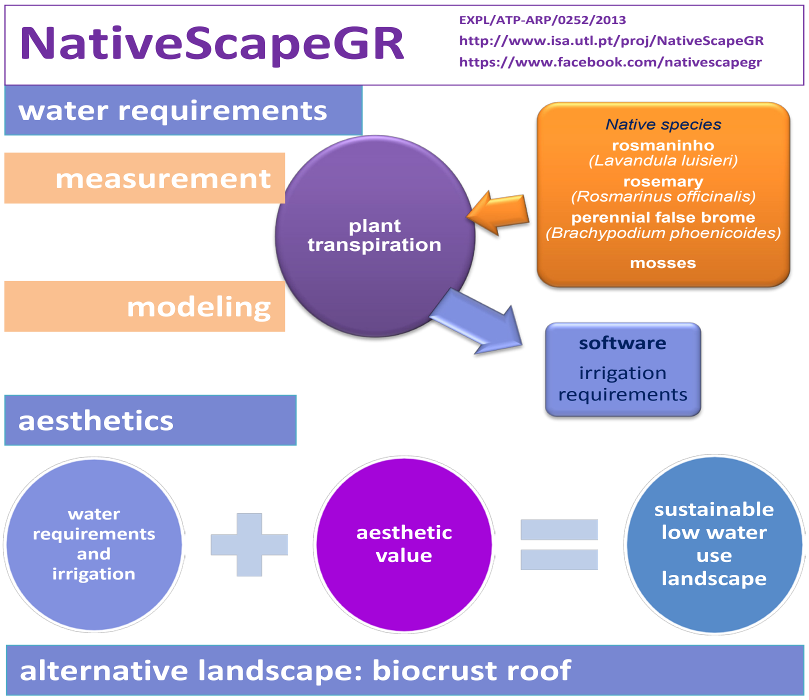

Figure 1 – Schematic description of the NativeScapeGR project.

3. EXPERIMENTAL DESIGN

The experimental design adopted in the project sets up treatments addressing low water requirements native species, including poikilohydric mosses, several irrigation levels (including a non-irrigated treatment), several substrates and aesthetic value assessment.

A set of drought adapted native plant species and bryophytes was chosen to quantify and model water requirements, while, in relation to this, their aesthetical value is assessed. Among the chosen species are the following perennial natives: rosmaninho (*Lavandula luisieri*), rosemary (*Rosmarinus officinalis*) and perennial false brome (*Brachypodium phoenicoides*) well adapted to Mediterranean climate conditions (plants were provided by Sigmetum, a Portuguese nursery specialized in native species). Furthermore, a selection of bryophytes (Table 1) with tolerance to desiccation was collected in nature and further transplanted using treatments with different regimes of irrigation, including rainfed ones.

In a first phase, rosmaninho, rosemary and perennial false brome plants were placed in 4 L pots with two different substrates and submitted to two different irrigation schemes (Table 1). Plants were planted in April 2014, placed outdoor and daily irrigated in equal amounts until 30th May, when two different irrigation levels started. The target irrigation levels were set at 60% of reference evapotranspiration (ET_o, [11]), 100 % ET_o, (calculated with historical meteorological data, 1971-2000) (Tables 1). This set up was used for a preliminary evaluation of water requirements for each species. Potted plants are probably in a similar situation to green roofs, in relation to substrate volume to be explored by roots, given the small depth of the substrates currently used in green roofs, although roots may explore larger horizontal areas. On the other hand, in green roofs, plants are likely more exposed to radiation and wind, what approximates the two situations. In a second phase, twelve metallic large trays (2.5 × 1.0 × 0.2 m) were installed at the top of the Herbarium building at ISA to simulate twelve green roofs (Table 2). Three different substrates (Table 3) were used with a substrate depth equal to 0.15 m. Plants were distributed according to Table 3. The target irrigation levels were set as in potted plants (Table 2). Since May 2014, actual meteorological data is used for computing ET_o, in order to adjust irrigation amounts (Figure 2). Meteorological data is collected in an automatic weather station within ISA campus, at a distance of 200 m.

vegetation	irrigation	substrates	number of repetitions
rosmaninho	60% ET_o	S1	3
		S2	3
	100 % ET_o	S1	3
		S2	3
rosemary	60% ET_o	S1	3
		S2	3
	100 % ET_o	S1	3
		S2	3
false brome	60% ET_o	S1	3
		S2	3
	100 % ET_o	S1	3
		S2	3

Table 1 – Experimental set up with potted plants in two different substrates and submitted to two irrigation levels; ET_o – reference evapotranspiration.

Tray reference	vegetation				irrigation	substrates
	rosmaninho	rosemary	false brome	mosses		
T1	✓	✓	✓	*Homalothecium* sp. *Brachythecium plumosum* *Pleurochaete squarrosa*	60% ET_o	S2
T2				*Homalothecium* sp. *Brachythecium plumosum* *Pleurochaete squarrosa*		S3
T3			✓			S2
T4	✓					S1+S3
T5	✓	✓	✓	*Pleurochaete* sp.		S1
T6		✓				S1
T7			✓			S1
T8		✓			100 % ET_o	S1
T9			✓			S1
T10	✓					S3
T11						S3
T12				*Neckera* sp. *Brachythecium plumosum* *Pleurochaete squarrosa*	no irrigation	S3

Table 2 – Experimental set up in trays with three different substrates and submitted to two irrigation levels or no irrigation; ET_o – reference evapotranspiration.

substrate	texture	pH	OM (%)	N ($g\ kg^{-1}$)	K_2O ($mg\ kg^{-1}$)	P_2O_5 ($mg\ kg^{-1}$)	FC ($cm^3\ cm^{-3}$)	WP ($cm^3\ cm^{-3}$)
S1	*	5	73	6	600	184	0.33	0.15
S2	sandy	7	7	1	218	126	0.22	0.12
S3	sandy	5	20	2	720	260	0.29	0.14

Table 3 – Characteristics of the substrates used in the experimental sets (OM – organic matter, N – nitrate content, K_2O – potassium content, P_2O_5 – phosphorous content, FC – field capacity, WP – wilting point, * not classified given the high OM content).

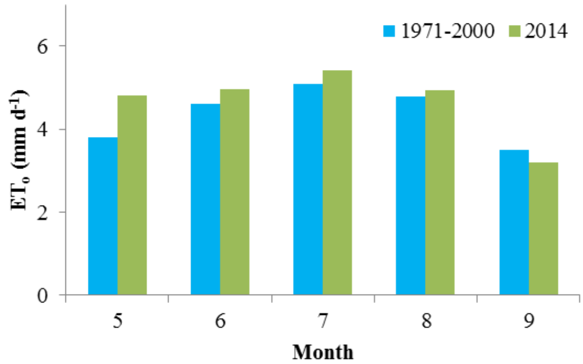

Figure 2 – Monthly mean daily reference evapotranspiration (ET_o) computed from data of the nearest weather station (Tapada da Ajuda); comparing historical data and data for the year 2014.

The methodological scheme currently implemented in the project has five sequential steps:

1. green roof installation at ISA campus – trays to simulate different green roofs were installed, filled with substrates and planted during May and June 2014; commercial drainage, filter and protection green roof elements were used to equip the trays (professional products and irrigation system supplied by Neoturf, Portugal);

2. collection and transplantation of mosses – a selection of appropriate moss species with desiccation tolerance traits were transplanted to trays and allowed to grow under controlled conditions of irrigation;

3. plant water requirements measurement – daily evapotranspiration (ET) was measured in potted plants during summer (from June to August) by means of weighing, just after irrigation and is continuously computed from soil water balance measurements in the trays; simultaneously, plant aesthetic value is periodically assessed and included in the beginning morphometric measurements; soil water measurement sensors (CS616 water content reflectometers, Campbell Scientific, USA) are being used in ten of the twelve trays to keep track of soil moisture status between irrigations or rainfall events and schedule irrigation, when appropriate, giving continuous information of the process over time;

4. assessment of hydrologic green roofs performance - following rainfall events, precipitation measurement, subsurface flow hydrographs, storm water retention evaluation and detention performance of the experimental green roof are performed, in order to model the water balance of the system and to propose optimal design for the green roofs, with respect to the hydrological performance.

5. landscape ET modelling – a model for computing water and irrigation requirements and supporting irrigation scheduling, using a crop coefficient approach [12], is currently being enhanced and *in situ* soil water content measurements will be used to calibrate and validate it.

4. PRELIMINARY RESULTS

4.1. Water requirements

An example of evapotranspiration results associated to the experimental set with potted plants is presented in Figure 3. For this case, two levels of irrigation are compared for the same plant (rosemary) and substrate (S1). For the lower irrigation level, average ET was 3.2 mm d^{-1}, while for the higher level it was 5.2 mm d^{-1}, for the summer period considered.

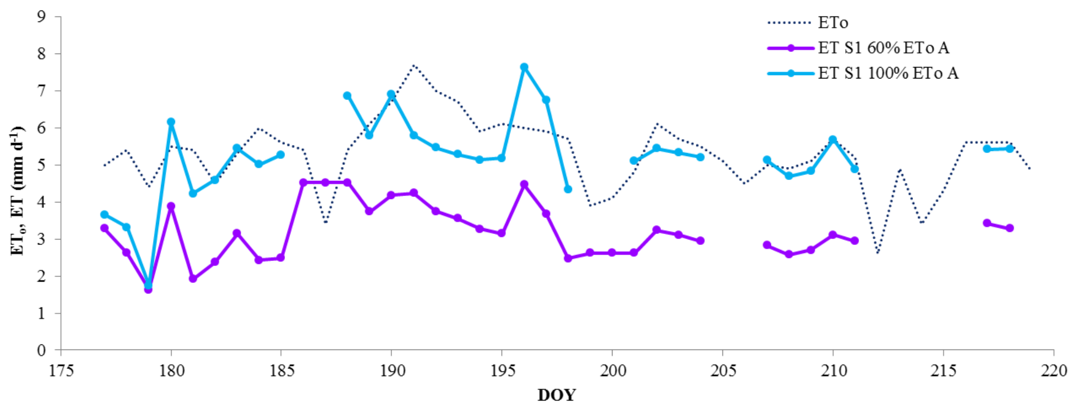

Figure 3 – Actual evapotranspiration in potted rosemary (*Rosmarinus officinalis*) plants submitted to two irrigation levels (60% of reference evapotranspiration, ET_o and 100% of ET_o).

Figure 4 presents evapotranspiration results for the same treatments of Figure 3, but for the green roof structure. Considering an identical period (DOY 192-198) for potted plants and the green roof, mean ET was 3.5 mm d^{-1} for the lower irrigation level in both plots. For the higher irrigation level, ET was higher in potted plants (5.7 mm d^{-1}) than in the green roof (4.1 mm d^{-1}). Either for potted plants or trays there are clear differences in evapotranspiration according to irrigation levels. Results in Fig. 3 and 4 agree with those recently reported by Snyder et al. (2015).

Figure 5 presents the ratio of ET_a to ET_o (for the same treatments of Figures 3 and 4), which in average is close to the target values of irrigation levels.

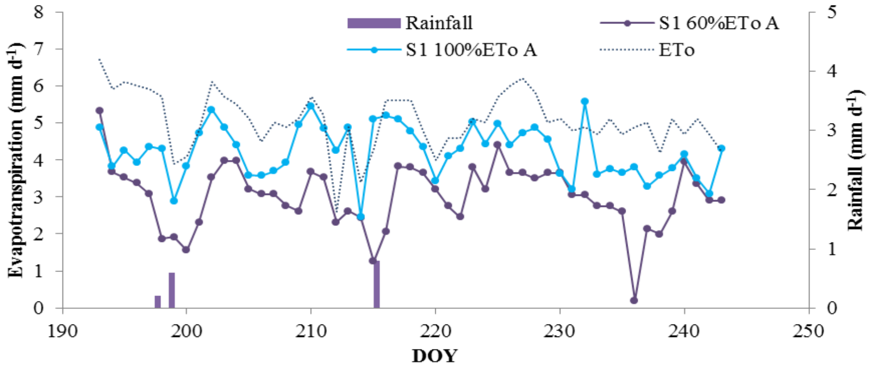

Figure 4 – Actual evapotranspiration in trays with rosemary (*Rosmarinus officinalis*) plants submitted to two irrigation levels (60% of reference evapotranspiration, ET_o and 100% of ET_o) and rainfall events.

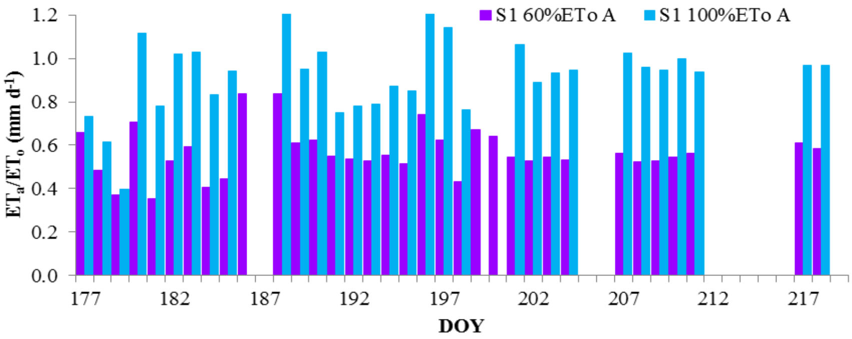

Figure 5 – Daily ratio of actual evapotranspiration (ET_a) to reference evapotranspiration (ET_o) for potted rosemary plants submitted to two irrigation levels.

4.2. Aesthetic evaluation

An example of some morphometric measurements for potted *Lavandula luisieri* is presented in Figure 6. In this case, different irrigation levels seem to induce only slight or no differences in development. Differences in flowering were detected for rosemary.

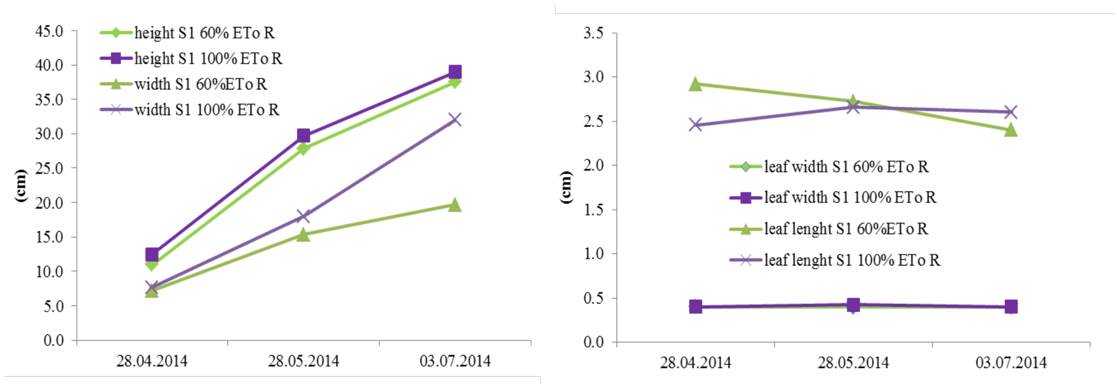

Figure 6 – Example of the morphometric evaluation results for *Lavandula luisieri*: plant height and width, leaf length and width.

4.3. Rainfall water retention

Figure 7 shows the rainfall water retention and the peak attenuation for three selected precipitations representing low, medium and high precipitation intensities. Table 4 shows some characteristics of the selected precipitation events and the correspondent runoff event times. The runoff results presented for each substrate are average values obtained from several trays.

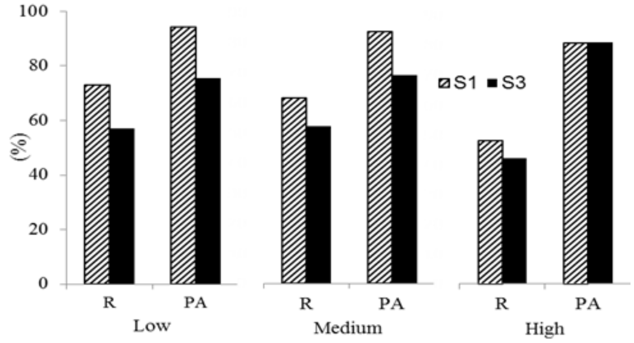

Figure 7 – Retention and peak attenuation for two different growing substrates.

	D h	A mm	PI mm h^{-1}	RD h	PD h
Substrate			Low I		
S1	2.9	7.2	8.0	1.5	2.9
S3				0.7	2.7
			Medium I		
S1	29.1	19.2	15.6	3.1	0.6
S3				3.0	0.4
			High I		
S1	46.9	59.6	84.0	5.4	0.1
S3				3.2	0.1

Table 4. Precipitation event characteristics and respective runoff times. D is the duration of the precipitation event, A is the amount of precipitation; PI is the precipitation peak intensity; RD is the runoff delay; PD is the runoff peak delay.

5. CONCLUDING REMARKS

Preliminary results of the NativeScapeGR project indicate that, in a general way, the two irrigation levels chosen did not impact visibly the species aesthetic value, although there were clear differences in evapotranspiration. Preliminary results show that, for low and medium precipitation intensities, substrate S1 performs better than S3. For high intensities, differences are not significant between substrates. For the non-irrigated treatment in the tray with bryophytes, where it was intended to study their development under rainfed conditions, mosses acquired a dry and brown aspect during summer. After the first rains in September they restarted activity, showing it was possible to maintain the selected species without irrigation in such conditions. A Biocrust Roof of this type could be an interesting solution for low-cost green roofs in urban areas with dry, hot summers.

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