Journal of Agricultural Science; Vol. 7, No. 11; 2015
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Performance of Two Simulated Green Roofs in the Mediterranean Area

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Received: August 1, 2015 Accepted: September 2, 2015 Online Published: October 15, 2015

doi:10.5539/jas.v7n11p59 URL: http://dx.doi.org/10.5539/jas.v7n11p59

Abstract

The green roofs sector is a relatively recent phenomenon in Mediterranean countries, meaning that as yet there is no complete understanding of which plants are suited to this particular environment. Such plants would need to be adaptable to the green roof itself as well as to the drought and intense lighting typical of a Mediterranean summer. Two simulated green roofs were planted with a variety of species and life forms and subjected to two minimal irrigation treatments and one treatment without irrigation. Mainly subshrub species were planted in one simulation, while the other contained a prevalence of groundcover species. The study looked at performance in terms of species, life forms, and simulation. We analysed flowering, mortality, frequency of planted species and of invasive species, and biomass. We took periodic measurements of cover and of the Shannon-Wiener vegetal diversity index. The groundcover species obtained a higher degree of cover, but suffered more from seasonal stresses. Both green roofs saw an increase in the abundance of a few species, leading to a simplification of the original design. Diversity and the ability to host colonising species were influenced mainly by differences in vegetational structure. Of the subshrub species, *Centranthus ruber* and *Helichrysum stoechas* performed best, while *Frankenia laevis* and *Thymus serpyllum* came top among groundcover species. In order to withstand severe drought stress, a minimal amount of irrigation was found to be necessary. Our study demonstrates that it is possible to obtain good results from a Mediterranean green roof by using an appropriate combination of vegetal species with different structures and development.

Keywords: coverage, diversity, drought stress, flowering, green roofs, mortality, vegetation structure

1. Introduction

Green roofs represent an ideal opportunity to improve the urban environment. They increase biodiversity in cities (Lundholm, 2006; Oberndorfer et al., 2007; Bass, 2009), lead to reduced energy costs for the buildings on which they are installed (Liu & Baskaran, 2003; Carter & Butler, 2008; Spala et al., 2008), and by absorbing rainwater they reduce stormwater runoff and the consequent overloading of drainage systems (Liu & Minor, 2005; Mentens et al., 2006; Stovin, 2010). The green roofs sector in Northern Europe has experienced more rapid development than its Mediterranean counterpart, and yet the Mediterranean area could benefit enormously from this technology (Benvenuti & Bacci, 2010; Ekşi & Uzun, 2013; Van Mechelen et al., 2014). The delay in implementing green roofs technology is related to specific climate conditions in the Mediterranean area, including high temperatures and prolonged droughts. Global warming could see temperatures rising both locally and across the entire area, and predicted climate changes mean that the Mediterranean area could benefit from the effects of increased vegetational cover (IPCC, 2013; Sheffield & Wood, 2008).

It is reasonable to assume that these negative effects will be felt even more in cities, due to increases in energy consumption and the urban heat island effect. In many large cities, including London and Hong Kong, green roofs are seen as an important instrument in the urban planner's attempts to combat the aforementioned effects (Townshend & Duggie, 2007; Greater London Authority, 2008; Van Lennep & Finn, 2008).

In the Mediterranean area, Barcelona has for years been working on projects aimed at improving the ecological connectivity of its urban spaces. One of these projects involves the use of green roofs and walls to create urban green corridors which will preserve a link between the city and surrounding natural environments (Àrea de Medi Ambient, Ajuntament de Barcelona, 2010, 2011).

One important characteristic of green roofs is that they improve public perceptions of the urban environment. This addresses one of the most deeply felt problems of city living, where the lack or scarcity of natural environments transforms inhabitant's appreciation of natural processes (Benvenuti, 2014). It is predicted that urban populations will increase in future decades, leading to a reduction in the space set aside for natural areas. This reduction can in part be countered by creating green habitats on the roofs of buildings. Benvenuti (2014) has trialled the performance of a number of wild flowers typical of Mediterranean landscapes with a green roof simulation designed to evaluate their biodiversity dynamics and bio-agronomic performance, going on to propose that they be used in green roofs in order to re-establish a relationship with the natural world and its seasonal variations.

The technical and cultural challenges represented by differences in climate conditions and urban settings mean that it is fundamental that more research be carried out to identify the species which are most adaptable to green roof environments in a Mediterranean climate and at the same time are able to withstand possible water shortages in the future. There have been a number of studies on the development of green roof vegetation over reasonably long periods, many of them concluding that plant diversity is dependent on the properties of the substrate (Bates et al., 2013; Thuring & Dunnett, 2014). Other studies have identified a relationship between the evolution of vegetation and the availability of water, as well as the depth of the substrate (Dunnett & Nolan, 2004; Getter & Rowe, 2009; Rowe et al., 2012).

The aim of this study was to analyse the performance of two simulated green roofs, each with different arrangements of plants, in a Mediterranean environment over a period of eighteen months. An arrangement of plants dominated by groundcover species and another dominated by subshrub species were each subjected to two different minimal irrigation protocols and to one protocol where the only water source was from rainfall. For the purposes of this study a number of agronomic, aesthetic, and functional parameters were recorded.

2. Materials and Methods

2.1 Study Site

The study took place between July 2010 and December 2011 at the IRTA (Institute for the Research of Food & Agricultural Technologies) in Caldes di Montbui (205 metres above sea level, 41°63'N 2°16'E), 30 km from Barcelona in Spain, along a Mediterranean coastal mountain range. Table 1 shows the principle climate data as measured during the study period, and Table 2 gives an overview of climate figures for the twenty years preceding this study.

Table 1. Monthly averages for the principle meteorological parameters during the study period (July 2010-December 2011) recorded at the Caldes de Montbui weather station (Barcelona)

	Temp. (ºC)			Rainfall (mm)	Et_o(mm)
	Mean	Min. recorded	Max. recorded		
July 2010	25.1	16.9	35.6	37.9	166.7
August 2010	23.5	14.6	37.9	47.3	141.5
September 2010	19.9	10.8	31.4	82.6	92.3
October 2010	14.9	1.5	25.9	136.5	64.6
November 2010	9.1	-2.5	22.9	15.3	38.5
December 2010	6.4	-4.4	20.0	47.7	25.3
January 2011	6.5	-6.3	19.7	28.8	31.3
February 2011	7.7	-2.2	21.1	16.1	41.4
March 2011	9.9	-1.3	21.6	193.0	64.5
April 2011	14.8	4.9	29.9	31.3	103.3
May. 2011	17.8	7.0	31.2	67.4	138.8
June 2011	20.1	10.2	31.9	70.3	134.1

July 2011	21.7	12.7	31.9	88.2	131.4
August 2011	23.4	13.8	34.6	10.4	146.5
September 2011	21.3	9.5	30.9	4.8	110.5
October 2011	16.7	4.5	31.7	69.3	73.5
November 2011	12.7	2.5	20.9	190.7	30.4
December 2011	7.4	-2.4	16.7	1.0	30.4

Table 2. Average climate figures recorded over a twenty years period at the study site* (average for each year from 1991 to 2010)

Year	Temp. (ºC)			Rainfall (mm)	ET_0 (mm)	Number of rainy days	Number of days < 0 ºC
	Mean	Max	Min				
1991	13.2	19.3	7.6				
1992	13.9	20.1	8.5	688.8	596.5	157	39
1993	13.9	20.3	8.4	625.0	816.3	179	41
1994	14.9	21.6	8.8	607.4	871.9	144	36
1995	14.7	21.1	8.7	520.8	803.4	163	21
1996	11.1	16.0	6.2	953.8	757.8	180	41
1997	15.1	21.6	9.3	592.7	838.2	141	15
1998	14.4	21.1	8.4	471.8	886.5	119	42
1999	14.5	21.3	8.4	473.6	806.1	119	50
2000	14.7	21.4	8.7	542.6	799.1	145	30
2001	15.0	21.7	8.9	280.4	877.3	143	32
2002	14.7	21.1	8.9	656.6	845.5	160	17
2003	15.4	22.0	9.4	551.6	882.0	138	36
2004	14.5	21.2	8.5	497.0	758.4	133	39
2005	14.1	20.9	8.0	611.0	925.2	140	83
2006	15.4	22.2	9.4	682.0	890.6	137	36
2007	15.1	22.4	9.0	405.3	806.6	71	23
2008	14.8	21.5	9.0	741.0	988.3	112	18
2009	15.2	22.1	9.2	541.9	1065.0	96	21
2010	14.2	15.6	12.9	743.0	998.5	29	21

Note. * data from the Caldes de Montbui weather station (MeteoCat http://www.meteo.cat/servmet/radar/).

2.2 Green Roof System

Each of the two simulated green roofs was planted with different combinations of species: one contained a majority of groundcover species, the other mostly subshrubs. Each green roof had a surface area of 54 m² divided into nine subplots measuring 6 m² each, three subplots for each irrigation treatment. Firstly the base of the structure was covered with a root barrier membrane and a polyethylene mat which served as a foundation upon which to build a ZinCo®system for extensive green roofs. The base layer of the system was an SSM 45 protection mat with an approximate water absorption capacity of 5 l/m^2. The protection mat was covered with a Floradrain®FD 25-E drainage and water storage element made of thermoformed recycled polyethylene with a storage capacity of approximately 10 l/m². The third layer was an SF thermally strengthened filter sheet made of polypropylene, followed by a 'Floral' type Zincoterra substrate (ZinCo Product List).

The floral substrate had an organic material content of approximately 5%, a bulk density value of 0.9, and 66% total porosity. pH values varied between 8.08 and 8.29 while electrical conductivity values ranged from 156.1 to

155.9 µS/cm (microSiemens/cm).

2.3 Experimental Design and Plant Selection

The number, arrangement and selection of species in each simulation were based on results obtained from a previous study carried out under the same conditions which analysed various parameters including coverage trend, biomass, and mortality (Vestrella et al., 2015). The experiment was performed using groundcover and subshrub species. Three plots were planted for each of the three irrigation protocols for a total of nine plots. Each of the nine main plots had a surface area of 12 m^2 which was divided into two sub-plots of 6 m^2 each (2 × 6 m). 61 plants representing 8 species were planted in each subshrub subplot, resulting in a density of 10 plants per square meter. 59 plants of 6 species were planted in each groundcover subplot, resulting in a density of 10 plants per square meter. The placement of the species was the same for every plot in each irrigation protocol. Plants in the subshrub subplots were placed randomly, although care was taken to ensure that each square metre contained at least one plant of each species. In the groundcover species subplots the plants were arranged in a grid, where one of two groundcover species (*Dymondia margaretae* and *Frankenia laevis*) was planted at each intersection of the grid. Another four species were planted inside the grid squares. Table 3 provides a list of the species used in the two green roof simulations, figure 1 shows the arrangement and layout of the plants.

Table 3. Species used in the two green roof simulations with number of plants for each species and common English names

Green roof with subshrubs		Green roof with groundcover	
Species	Number of plants	Species	Number of plants
Helichrysum stoechas (L.) Moench Common shubbry everlasting	10	*Frankenia laevis* L. Sea heath	17
Santolina rosmarinifolia L. Green lavander cotton	10	*Dymondia margaretae* Compton Silver carpet	18
Drosanthemum floribundum (Haw.) Schwantes. Pale dew-plant	5	*Limonium virgatum* (Willd.) Fourr. Violeta sea lavender	6
Armeria maritima (P. Mill.) Willd. Sea thrift	11	*Thymus serpyllum* L. Breckland Thyme	6
Lotus creticus L. Creta trefoil	5	*Drosanthemum floribundum* (Haw.) Schwantes Pale dew-plant	6
Centranthus ruber (L.) DC. Red valerian	5	*Asteriscus maritimus* (L.) Less. Sea daisy	6
Asteriscus maritimus (L.) Less. Sea daisy	5		
Iris lutescens Lam. Crimean iris	10		
	Total: 61		**Total: 59**

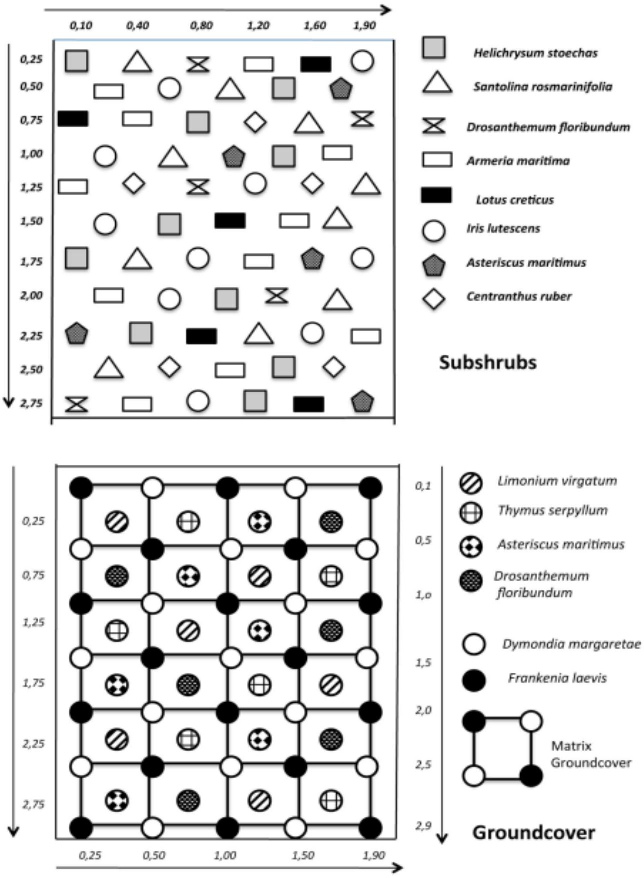

Figure 1. Arrangement of plants according to species, showing layout and distances

2.4 Irrigation

Three different irrigation protocols were used: rainfed (no use of artificial irrigation, 0% ET_0); resupply of 20% of water lost to potential evotranspiration (20% ET_0); and resupply of 40% of the same (40% ET_0). Potential evotranspiration (ET_0) was calculated at the Caldes de Montbui weather station two hundred metres from the study site. Each week a calculation was made of how much water to supply to the plants by subtracting the total amount of precipitation during the previous week from the total value of ET_0. The resulting amount of water was distributed evenly throughout the week. Water was supplied by drip emitting tubes placed on the surface of the soil. The tubes were placed at a distance of 40 cm from each other and had a diameter of 16 mm with a flow rate of 22.8 litres m^{-2} $hour^{-1}$.

2.5 Green Roof Measurements

The following parameters were measured: percentage of mortality, vegetational cover of soil, flowering, final biomass of roots and of upper sections. Vegetational diversity trends were calculated, as well as the presence of single species throughout the trial, taking into account colonising species as well as those which were intentionally planted. Measurements were taken for each individual species and for the green roof as a whole.

Plant mortality was recorded each month. Plants without living stems or leaves were considered dead even though they were left in place so as to observe any appearance of new shoots.

Green cover was measured using a Nikon EOS 500 digital camera mounted on a tripod, and a laptop computer running the Greenpix software developed by the IRTA (Institute for Food and Agricultural Research and Technology) for the analysis of digital imagery (Casadesús et al., 2005, 2007). The green roof was photographed once a month using an 18 mm lens mounted on a tripod arm 2.5 m from the ground. The camera was connected to a laptop running Nikon EOS software, making it possible to remotely adjust the image and activate the shutter. Diaphragm aperture remained constant throughout, and the photographs were taken between 11am and 2pm so as to avoid long shadows.

The images were then processed with the Greenpix software. This software makes it possible to identify colour variations between pixels within a 0° to 180° hue range. It is possible within this range to calculate the number of yellow, green, and brown pixels and the percentage of total pixels represented by each colour. The surface area represented by each pixel was calculated and translated into square centimetres so as to obtain the total surface area for each plant colour.

Total plant cover surface was calculated by identifying all pixels between 40° and 180°, equivalent to green and some brown tones.

Duration of flowering was calculated for each green roof and for all species by making monthly observations during the first year and every fifteen days from April to October of the second year. Biomass was measured on completion of the study period by removing the plants from the soil, cleaning them, and placing them in a ventilated oven at 65º centigrade for seven days. Roots and upper sections were then weighed separately.

The presence of each species in the green roofs was measured every two months by superimposing a grid onto the photographs used to measure vegetational cover. Photoshop CS was used to place a grid of 96 nodes on a photograph of each of the three repetitions of irrigation treatments. The species of plants present at each node, or grid intersection, were recorded. Species identifications made using the photographs was then verified on site.

The results thus obtained made it possible to calculate the presence of each species in each subplot, as well as the presence of colonising species in order to understand how they influenced the evolution of the two green roofs. We were likewise able to calculate the diversity index by applying the Shannon Wiener formula:

$$Diversity\ (H') = -S(ni/N) \times \ln(ni/N) \qquad (1)$$

This index is based on the amount of species in each subplot (richness) and the number of plants of each species (abundance). The index is relative and indicates the degree of difference or similarity between different specimens. In our study the values recorded in July 2010 represent the initial values, or those which correspond to vegetational diversity at the moment of planting in the two green roofs. The initial value of the subshrubs section was higher because a greater number of species were planted (Table 3).

2.6 Statistical Analysis

The experiment was a factorial design with three factors: irrigation treatment, sampling date and subplot. The mixed model used for analysing the plant cover in each green roof included the following fixed effects: sampling date, irrigation treatments and the interaction between sampling date and irrigation, whereas the random effects were subplots and the interaction between subplot and irrigation. Three levels were set for irrigation, seventeen for sampling date and three for the subplots. The Tukey pairwise comparison post-hoc test was used to identify mean values that were different with a probability of 0.05 or less in the main factors (irrigation and sampling date). To compare irrigation treatments for a single sampling date, a slice was performed on the interaction by sampling date when interactions were significant. The analysis was carried out using the SAS 9.4 software. Average mortality rates, total cover, and biomass for each irrigation treatment and both green roof simulations were compared using the Tukey Kramer HSD test and JMP 10 software.

3. Results

3.1 Mortality

Figure 2 shows mortality trends throughout the study period. The highest final mortality rates in both green roofs were registered for the areas with no artificial irrigation. There were no significant differences in average mortality rates between the three different irrigation treatments in the subshrub green roof. For the groundcover green roof, average mortality rates in the irrigated sections were significantly (significance level $P < 0.05$) different from those of the plants which received no irrigation (Table 4).

Table 4. Average mortality percentages throughout the entire study period for the three irrigation treatments (0%, 20% and 40% ET_0) in both green roofs (subshrubs and groundcover). Comparison between average percentages was made using the Tukey-Kramer HSD Test (significance level $P < 0.05$). Significant differences in data are represented by different alphabetical letters

	Subshrubs	Groundcover
0% ET_0	47,397 A	47,352 A
20% ET_0	41,632 A	24,833 B
40% ET_0	41,014 A	21,529 B

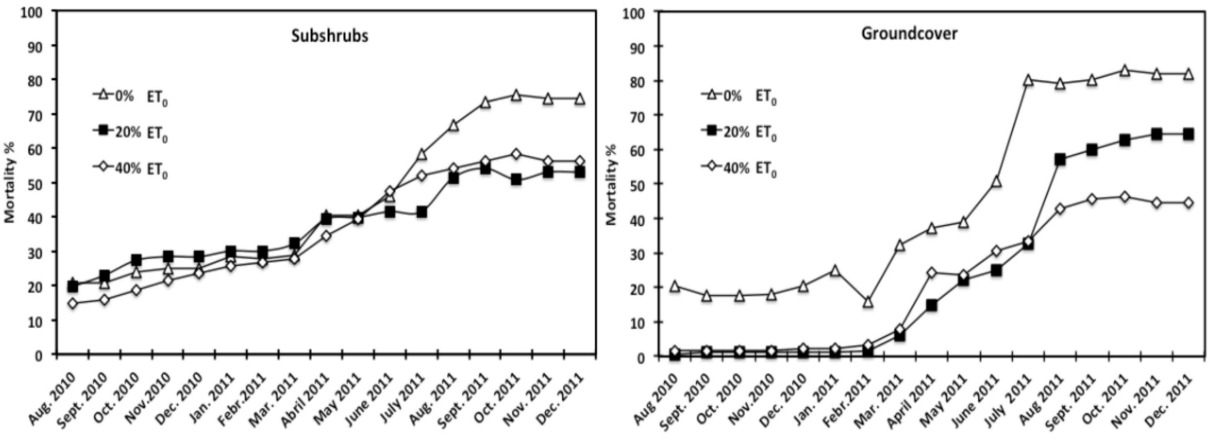

Figure 2. (2a. Subshrubs; 2b. Groundcover) Mortality percentages for the two green roofs between August 2010 and December 2011 for 0%, 20% and 40% ET_0 irrigation treatments

3.2 Vegetation Cover

In the green roof containing subshrub species, soil cover increased from April 2011 in the irrigated plots, while soil cover of the plants which received no irrigation began to fall after June 2011 (Figure 3a).

In the green roof simulation containing groundcover species, soil cover was at its highest in the summer and autumn months for the irrigated plots (Figure 3b). Non-irrigated plants in both simulations achieved a lower soil coverage. The green roof with groundcover species showed wider variations in cover than the green roof with subshrub species, particularly during winter months.

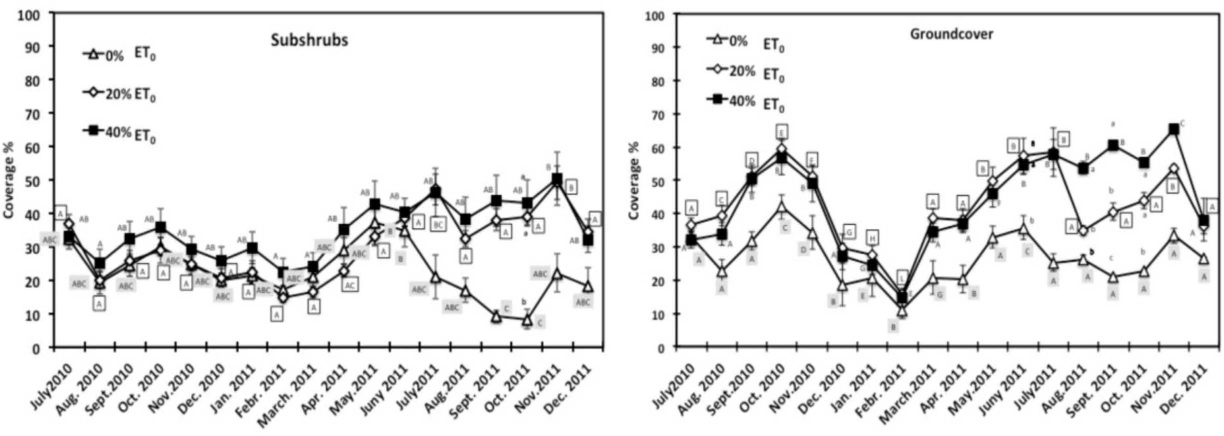

Figure 3. (3a. Subshrubs; 3b. Groundcover). Evolution of cover (percentages ± SE) between July 2010 and December 2011 for the three irrigation treatments of 0%, 20% and 40% ET_0 in the two green roof simulations (groundcover and subshrubs). Different upper-case letters indicate significant differences between one data collection date and another for the same irrigation treatment. Different lower-case letters indicate significant difference between different irrigation treatments for the same data collection date (significance level $P < 0.05$)

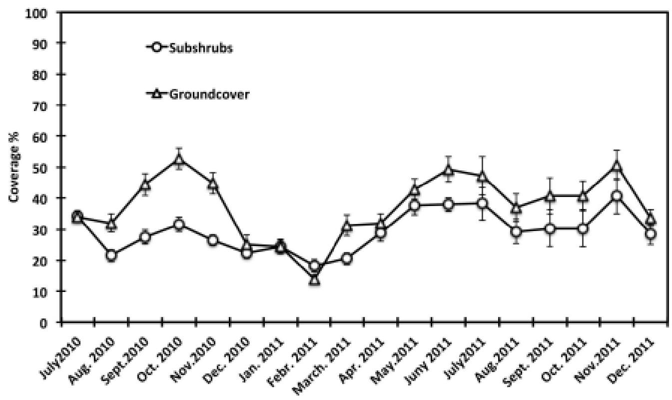

Figure 4. Evolution of cover (percentages ± SE) between July 2010 and December 2011 for the two green roofs (groundcover and subshrubs). Each value represents an average of all three irrigation treatments 0%, 20% and 40% ET_0

A comparison between vegetation cover in the two green roofs, made through monthly observations of average values of all three irrigation treatments reveals higher increases for the groundcover species (Figure 4).

3.3 Flowering

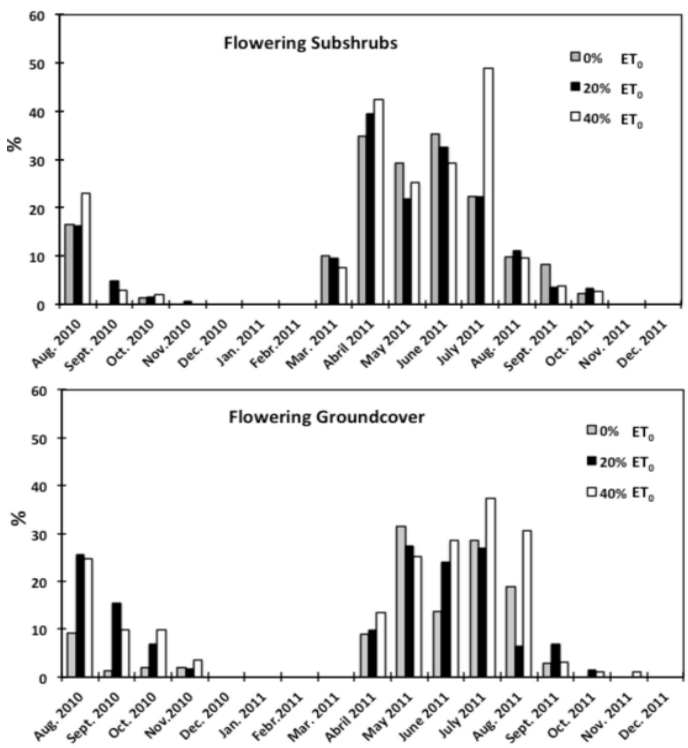

Figure 5. (above: Subshrubs below: Groundcover) Flowering rates for the three irrigation treatments (0, 20 and 40% ET_0) from August 2010 to December 2011. Values were calculated monthly for the total number of living plants

Flowering in the two green roofs was more intense and prolonged in the 40% ET_0 irrigated plots, especially during the hottest period. Flowering of the groundcover species lasted until August while that of the subshrub species ended in July (Figures 5a and 5b).

Table 5 shows the flowering results for each species in the two simulations and total duration of flowering in months.

Table 5. Evolution of flowering during the study period. Each value indicates the number of plants in bloom for each species and for each irrigation treatment (0, 20 and 40% ET_0) from August 2010 to December 2011 for the two green roof simulations (Subshrubs above - Groundcover below). The column on the right shows the total number of months of flowering

		Aug. 2010	Sept. 2010	Oct. 2010	Nov.2010	Dec. 2010	Jan. 2011	Febr.2011	Mar. 2011	Abril 2011	May 2011	June 2011	July 2011	Aug. 2011	Sept.2011	Oct. 2011	Nov. 2011	Dec. 2011	TOT-MONTHS
SUBSHRUBS																			
Armeria maritima	0%ET_0	10							6	14	6	1							*5*
	20%ET_0	10							4	26	3	2							*5*
	40%ET_0	18							4	24	1		2	1					*6*
Asteriscus maritimum	0%ET_0	6								5	6		1						*4*
	20%ET_0	6	6	2						7	5	4	3	3					*8*
	40%ET_0	9	1	2						7	7	4	2		1				*8*
Centranthus ruber	0%ET_0	2		2						9	9	5	4	6	2				*8*
	20%ET_0	2	1							6	11	4	6	7	3	2			*9*
	40%ET_0	2	3	1						5	9	2	5	4	1	1			*10*
Drosanthemum floribundum	0%ET_0																		*0*
	20%ET_0									2									*1*
	40%ET_0									1			5						*1*
Helichrysum stoechas	0%ET_0	6								4	4	23	12		2	1			*7*
	20%ET_0	6								3	5	25	15			1			*6*
	40%ET_0	7								4	9	19	10	3	1	1			*8*
Iris lutescens	0%ET_0								7										*1*
	20%ET_0				1				8										*2*
	40%ET_0								6				4						*2*
Lotus creticus	0%ET_0																		*0*
	20%ET_0																		*0*
	40%ET_0												5						*1*
Santolina rosmarinifolia	0%ET_0									6	7	6							*3*
	20%ET_0																		-
	40%ET_0									10	2	3	10						*4*
GROUNDCOVER																			
Limonium virgatum	0%ET_0	8	2									2	4	1					*5*
	20%ET_0	16	13									14	12	3					*5*
	40%ET_0	15	7	7								10	17	11					*6*
Thymus serpillum	0%ET_0	2	0	2	3							4	3	4					*6*
	20%ET_0	15	10	6	2					1		7	17		2				*8*
	40%ET_0	16	10	10	6					4		15	18	14					*8*
Asteriscus maritimus	0%ET_0	3	0	1						9	11	6	3	2	1				*8*
	20%ET_0	14	4	6	1					13	15	11	3	2	2	1			*11*
	40%ET_0	12								13	14	9	9	6	3	1	1		*9*
Drosanthemum floribundum	0%ET_0									1									*1*
	20%ET_0									1	1								*2*
	40%ET_0									1	1								*2*
Dymondia margaretae	0%ET_0																		-
	20%ET_0																		-
	40%ET_0																		-
Frankenia laevis	0%ET_0										23								*1*
	20%ET_0										21				1				*2*
	40%ET_0										19	1							*2*

3.4 Biomass

There were no significant differences in biomass between different irrigation treatments in the two simulations. Groundcover species revealed a greater biomass than that of the subshrubs (Table 6).

Table 6. Dry biomass weight values (± SE) of different plant parts for each irrigation treatment (0, 20 and 40% ET_0). Each value is calculated for the total number of living plants. The number of living plants is shown in the first column. Average values not associated with the same letter are significantly different at $p < 0.05$ (Test Tukey Kramer HSD)

Irrigation	Nº plants	Aboveground (g)		Roots (g)		Total (g)	
		Total	Mean	Total	Mean	Total	Mean
GROUNDCOVER 0%ET_0	14	1097,2	78,4 ±40,9 A	331,1	23,6 ±11,7 A	1428,2	102,0 ±52,2 A
GROUNDCOVER 20% ET_0	18	2487,0	138,2 ±49,2 A	371,5	20,6 ±5,5 A	2858,5	158,8 ±53,9 A
GROUNDCOVER 40% ET_0	32	2671,9	83,5 ±26,3 A	748,0	23,4 ±5,7 A	3419,9	106,9 ±31,5 A
SUBSHRUBS 0%ET_0	23	135,7	5,9 ±1,5 A	98,9	4,3 ±1,1 A	234,6	10,2 ±2,2 A
SUBSHRUBS 20% ET_0	49	1129,1	23,0 ±5,6 A	418,2	8,5 ±1,8 A	1547,3	31,6 ±6,8 A
SUBSHRUBS 40% ET_0	43	1212,2	28,2 ±8,6 A	229,8	5,3 ±0,9 A	1442,1	33,5 ±9,4 A

3.5 Plant Diversity

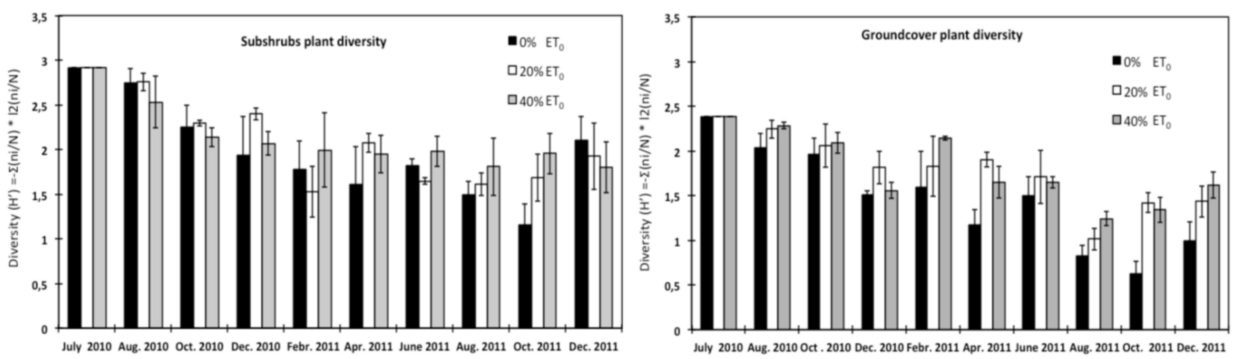

Figure 6. (6a. Subshrubs; 6b. Groundcover) Plant diversity trends calculated with the Shannon Wiener index for three irrigation treatments (0, 20 and 40% of ET_0) from August 2010 to December 2011. Data was retrieved twice monthly beginning in July 2010

Figure 6 shows plant diversity trends for both green roofs calculated with the Shannon Wiener index (H') throughout the entire trial period. In both trials diversity rates fell with respect to the initial values, especially for the non-irrigated plots (with exceptions among the subshrub species).

3.6 Species Presence

Tables 7 and 8 show the evolution of the presence of all plant species in the two trials throughout the study period. In the subshrubs trial there was a reduction in the number of planted species for all irrigation treatments.

Table 7. Presence rate (% ± SE) of all species for three irrigation treatments (0, 20 and 40% ET_0) from August 2010 to December 2011 calculated for the subshrubs simulation green roof. The data was collected twice monthly for species planted at the beginning of the trial and for colonising species. Data was collected from July 2010

			July 2010	Aug. 2010	Oct. 2010	Dec. 2010	Febr. 2011	Apr. 2011	June 2011	Aug. 2011	Oct. 2011	Dec. 2011
Armeria maritima	planted	0%ET_0	11,5	2,4 ±0,7	0,3 ±0,3	0,7 ±0,3	1,0 ±0,6	0,7 ±0,7	0,7±0,7			
		20%ET_0	11,5	3,8 ±2,1	0,7 ±0,7		0,3 ±0,3	1,0 ±0,6				
		40%ET_0	11,5	1,4 ±0,7	0,7 ±0,3	0,7 ±0,7	1,0 ±0,6	0,7 ±0,7	0,3±0,3		0,3 ±0,3	0,3 ±0,3
Asteriscus maritimus	planted	0%ET_0	5,2	3,1 ±1,2	3,1 ±2,2	2,4 ±1,5		1,4 ±1,4	1,4±1,4	0,3 ±0,3		0,3 ±0,3
		20%ET_0	5,2	5,6 ±1,3	5,2 ±3,7	5,9 ±2,3		3,5 ±1,9	2,8±2,8	2,8 ±2,8	1,4 ±1,4	2,8 ±2,3
		40%ET_0	5,2	3,8 ±0,9	4,9 ±1,3	3,5 ±0,3	1,4 ±0,7	1,4 ±0,3	1,7±0,9		1,7 ±0,9	0,7 ±0,7
Centranthus ruber	planted	0%ET_0	5,2	4,5 ±1,7	9,0 ±4,9	6,3 ±3,1	1,7 ±0,3	6,9 ±3,4	16,7±7,4	16,7 ±3,7	7,3 ±3,0	8,0 ±3,0
		20%ET_0	5,2	4,5 ±0,7	7,3 ±1,8	4,5 ±1,9	1,0 ±0,6	9,7 ±3,1	13,2±2,8	11,1 ±4,0	16,0 ±4,5	12,5 ±5,8
		40%ET_0	5,2	4,9 ±1,3	5,9 ±3,0	3,1 ±3,1	1,0 ±0,6	4,9 ±1,8	4,9±1,8	2,4 ±0,9	3,5 ±0,7	2,4 ±0,3
Drosanthemum floribundum	planted	0%ET_0	5,2	4,9 ±0,3	6,6 ±0,9	0,7 ±0,7	4,5 ±1,7	1,0 ±1,0	0,3±0,3			
		20%ET_0	5,2	4,5 ±0,7	3,8 ±1,3	1,4 ±0,9	2,1 ±0,0					
		40%ET_0	5,2	4,5 ±0,3	2,8 ±1,8	0,0 ±0,0	4,5 ±1,5					
Helichrysum stoechas	planted	0%ET_0	10,4	2,4 ±0,9	2,8 ±0,9	2,8 ±0,9	4,2 ±1,2	7,6 ±3,9	12,5±3,9	8,0 ±4,6	3,5 ±1,9	2,8 ±0,9
		20%ET_0	10,4	6,3 ±0,6	5,9 ±1,3	5,6 ±0,9	8,3 ±1,0	13,5 ±0,0	18,4±0,9	17,4 ±0,9	14,2 ±6,8	10,1 ±4,0
		40%ET_0	10,4	4,2 ±0,6	2,4 ±0,9	4,2 ±0,6	3,1 ±1,2	3,8 ±1,5	13,9±2,8	15,6 ±2,6	16,0 ±0,3	12,2 ±1,9
Iris lutescens	planted	0%ET_0	10,4	2,8 ±0,3	0,3 ±0,3		0,3 ±0,3	1,7 ±0,9	1,0±0,6			1,0 ±0,6
		20%ET_0	10,4	1,7 ±1,6		2,1 ±2,1	0,7 ±0,7	0,7 ±0,7	0,7±0,3		0,3 ±0,3	
		40%ET_0	10,4	1,4 ±0,9		2,1 ±1,0	1,0 ±0,6	2,1 ±1,0	0,7±0,3	0,7 ±0,7	0,3 ±0,3	0,7 ±0,7
Lotus creticus	planted	0%ET_0	5,2	3,8 ±0,7	4,9 ±1,5	5,9 ±2,4			0,3±0,3			
		20%ET_0	5,2	5,2 ±0,6	9,4 ±1,6	3,5 ±0,3						
		40%ET_0	5,2	5,6 ±0,3	10,1 ±1,3	9,0 ±3,1		6,9 ±6,9				
Santolina rosmarinifolia	planted	0%ET_0	10,4	7,6 ±4,0	10,4 ±6,3	8,3 ±5,9	9,4 ±7,4	13,5 ±9,7	8,3±8,3	2,4 ±2,4		
		20%ET_0	10,4	6,6 ±3,5	1,4 ±1,4	1,7 ±1,3	0,7 ±0,7	0,7 ±0,7				
		40%ET_0	10,4	14,9 ±6,1	18,1 ±7,3	15,6 ±5,9	13,9 ±5,3	17,7 ±3,7	11,8±11,8	5,6 ±5,6		
Conyza bonariensis	colonizing	0%ET_0								0,3 ±0,3		
		20%ET_0						0,3 ±0,3	0,7±0,7	0,3 ±0,3	2,1 ±1,0	1,7 ±1,3
		40%ET_0							1,0±0,6	5,9 ±2,8	10,8 ±2,7	4,5 ±2,3
Frankenia laevis	colonizing	0%ET_0									0,3 ±0,3	0,5 ±0,5
		20%ET_0									0,3 ±0,3	0,3 ±0,3
		40%ET_0										0,3 ±0,3
Gramínies spp	colonizing	0%ET_0								0,3 ±0,3	0,7 ±0,7	
		20%ET_0										
		40%ET_0										
Lactuca perennis	colonizing	0%ET_0										5,2 ±3,0
		20%ET_0										
		40%ET_0										

Oxalys corniculata	colonizing	0%ET_0										1,0 ±1,0
		20%ET_0										2,4 ±1,3
		40%ET_0										
Sonchus oleraceus	colonizing	0%ET_0			0,3 ±0,3	0,3 ±0,3		0,3 ±0,3	1,7±1,7			3,5 ±2,1
		20%ET_0				1,4 ±1,4	0,3 ±0,3	2,1±1,0				
		40%ET_0				0,3 ±0,3			2,3±0,8	1,0 ±1,0	1,7 ±1,7	2,1 ±2,1
Thymus serpyllum	colonizing	0%ET_0						0,7 ±0,7	3,1±1,2	1,7 ±0,9		0,5 ±0,5
		20%ET_0						2,1±1,2	9,0±5,8	14,6 ±6,8	20, ±10,7	17, ±10,1
		40%ET_0					0,3 ±0,3	4,9 ±4,4	12,8 ±6,7	23,6±10,2	29,2±10,7	25, ±14,2

At the end of the trial the species with highest survival rates were *Centranthus ruber* and *Helichrysum stoechas* along with small quantities of other surviving species, mostly in the 40% ET_0 plot.

In the non-irrigated portions of the groundcover green roof the reduction of species became more severe from June 2011. The surviving species at the end of the trial were *Frankenia laevis*, *Asteriscus maritimus* and *Thymus serpyllum*.

Among the irrigated plants the highest presence values were achieved by *Thymus serpyllum* and *Frankenia laevis* and to a lesser degree by *Asteriscus maritimus.* A minimal presence of other species was also observed. Plant presence values were higher in the 40% ET_0 irrigated plots.

Colonising plants in the subshrubs green roof saw an increased presence from April 2011. Throughout the study period seven species were counted in the non-irrigated subplots. Five species were counted in the 20% ET_0 plots and 4 in the 40% plots. *Thymus serpyllum* was the species which reached the highest level of presence in the 20% and 40% ET_0 plots. The abundance of this species could be due to transfer from the nearby groundcover green roof.

The presence of colonising species in the groundcover green roof was minimal both in terms of number of species and in terms of presence: three species were observed in the non irrigated plots and in the 40% ET_0 plots, and two species were observed in the 20% ET_0 plots.

Table 8. Presence rate (% ± SE) of all species for three irrigation treatments (0, 20 and 40% of ET_0) from August 2010 to December 2011 calculated for the groundcover simulation green roof. The data was collected twice monthly for species planted at the beginning of the trial and for colonising species. Data was collected from July 2010

			July 2010	Aug. 2010	Oct. 2010	Dec. 2010	Febr. 2011	Apr. 2011	June 2011	Aug. 2011	Oct. 2011	Dec. 2011
Asteriscus maritimus	planted	0%ET_0	6,3	3,8 ±0,7	4,2 ±0,6	3,5 ±0,3	0,3 ±0,3	2,8 ±1,5	2,8 ±1,5	1,0 ±0,6	0,7 ±0,3	1,0 ±1,0
		20%ET_0	6,3	6,3 ±0,0	10,8±0,3	6,6 ±0,3	1,4 ±0,9	3,5 ±1,3	3,1 ±2,2	1,0 ±1,0	3,1 ±1,6	2,4 ±0,9
		40%ET_0	6,3	4,9 ±1,5	6,9 ±2,3	6,3 ±1,0		4,5 ±1,5	5,6 ±0,9	6,3 ±1,8	6,3 ±2,2	4,9 ±1,4
Drosanthemum floribundum	planted	0%ET_0	6,3	5,2 ±1,0	9,7 ±0,3	8,7 ±8,7	3,8 ±2,3	0,3 ±0,3	2,4 ±2,4			
		20%ET_0	6,3	3,1 ±1,2	3,8 ±2,3	0,3 ±0,3	1,4 ±1,4	4,2 ±3,1	0,3 ±0,3			
		40%ET_0	6,3	5,6 ±0,3	4,9 ±1,3		3,8 ±0,7	1,0 ±1,0				
Dymondia margaretae	planted	0%ET_0	18,8	8,3 ±1,6	4,2 ±1,0	1,7 ±1,3	3,1 ±3,1			0,3 ±0,3		
		20%ET_0	18,8	9,4 ±0,6	5,9 ±2,5	4,2 ±2,8	4,9 ±2,7	1,7 ±0,9	0,3 ±0,3			
		40%ET_0	18,8	10,1 ±1,4	5,6 ±1,5	0,7 ±0,7	6,3 ±0,6	1,7 ±0,9	1,0 ±1,0	0,3 ±0,3		0,3 ±0,3
Frankenia laevis	planted	0%ET_0	17,7	20,8 ±3,1	26,4 ±4,6	24,0±3,0	6,9 ±4,4	32,6 ±7,2	24,7 ±1,8	23,3 ±0,9	19,1 ±1,5	22,9 ±1,6
		20%ET_0	17,7	22,9 ±2,4	28,8 ±5,9	30,9 ±2,1	5,9 ±2,5	29,5 ±0,7	27,1 ±5,9	17,0 ±5,9	22,9 ±5,3	21,2 ±4,8
		40%ET_0	17,7	22,2 ±3,9	27,4 ±5,1	33,3 ±7,1	6,3 ±2,4	31,6 ±6,4	21,2 ±2,5	19,4 ±8,2	21,2 ±7,5	19,4 ±6,1

Limonium virgatum	planted	0%ET_0	6,3	0,7 ±0,7	1,0 ±0,6	1,4 ±0,7	1,0 ±0,6	1,4 ±0,9	0,7 ±0,3	0,3 ±0,3		0,3 ±0,3
		20%ET_0	6,3	4,2 ±1,6	2,1 ±1,2	4,2 ±2,2	2,4 ±0,9	4,9 ±1,5	4,5 ±1,9			0,7 ±0,7
		40%ET_0	6,3	3,1 ±1,8	2,8 ±0,3	2,8 ±0,9	3,8 ±0,3	2,8 ±0,7	5,6 ±0,9		0,3 ±0,3	2,1 ±0,6
Thymus serpyllum	planted	0%ET_0	6,3	5,6 ±1,5	5,2 ±0,6	4,2 ±2,2	3,8 ±1,5	8,3 ±1,6	16,3 ±2,8	1,7 ±0,9		0,3 ±0,3
		20%ET_0	6,3	12,2 ±0,9	16,3 ±1,3	16,3 ±1,9	10,8 ±1,8	22,6 ±3,3	26,7 ±6,1	8,7 ±3,7	21,5 ±6,2	19,8 ±6,9
		40%ET_0	6,3	14,6 ±1,8	19,4 ±3,3	15,3 ±3,6	12,2 ±1,3	24,3 ±0,9	36,1 ±2,1	34,0 ±4,9	35,1 ±6,0	28,5 ±3,9
Conyza bonariensis	colonizing	0%ET_0							0,3 ±0,3	0,3 ±0,3	1,0 ±1,0	
		20%ET_0							2,8 ±1,5	0,7 ±0,7	2,4 ±1,3	1,0 ±0,6
		40%ET_0								1,0 ±0,6		0,3 ±0,3
Lactuca perennis	colonizing	0%ET_0										2,8 ±1,3
		20%ET_0										
		40%ET_0										
Sonchus oleraceus	colonizing	0%ET_0							0,3 ±0,3	0,7 ±0,7	1,0 ±1,0	1,0 ±0,7
		20%ET_0			0,3 ±0,3			0,7 ±0,3	0,3 ±0,3	0,3 ±0,3	0,7 ±0,7	1,0 ±0,6
		40%ET_0				0,3 ±0,3					1,0 ±0,6	1,4 ±0,3
Santolina chamaecyparissus	colonizing	40%ET_0						0,7 ±0,7	1,0 ±1,0			

4. Discussion

The green roof containing groundcover species obtained a higher level of cover that the green roof with subshrub species, a situation which can be explained by structural differences between the two species groups: the subshrubs tend to develop more in terms of volume while the groundcover species grow horizontally and superficially. In the field of green roofs research, differences in biomass and foliage have been shown to have an influence on coverage, but they are also very important with regard to the improvement of the thermic and hydrological performance of a roof. Detailed in-depth studies have revealed that plants with different structures achieved different results with regard to thermic isolation and rainwater retention (Del Barrio, 1998; Jim, 2011; Nagase & Dunnett, 2012). For both green roofs irrigation was seen to have an influence on vegetation cover. The irrigated plants predictably achieved a higher degree of cover than those which were not irrigated. Higher levels of cover depended more on the number of surviving plants than on the development of individual plants, although only the groundcover species displayed significant differences in mortality between irrigated and non-irrigated plants. Biomass figures confirmed previous data, with higher values for the groundcover green roof and for the irrigated plants, with no significant differences in average values between the two irrigation treatments (20 and 40% ET_0). This suggests that the minimum amount of irrigation to provide could be somewhere between the evotranspiration percentages of the two irrigation treatments, an observation which could help to estimate the amount of water consumed by a green roof in a Mediterranean environment. All the same, our study recommends maintaining a minimum level of irrigation in order to achieve the levels of vegetation cover required by green roofs standards (FLL, 2008).

Another important element is the reduction in planted species that took place from June 2011. The subshrub species which survived after June 2011 were two suffruticose chamaephytes species: *Centranthus ruber, Helichrysum stoechas*, whereas the surviving groundcover species were reptant chamaephyte species: *Frankenia laevis* and *Thymus serpyllum*. The Raunkiær life-forms system, which classifies species according to the different bud placements, can be used to select mediterranean plant species appropriate for green roofs according to their principle characteristics (Caneva et al., 2013; Van Mechelen et al., 2014). This result is compatible with the general criteria proposed by Schulze et al. (2005), which cites suffruticose chamaephytes as being among the plants that display reduced transpiration. Generally, we have seen that the species which survived in our trial also performed well in numerous other studies on green roofs in a mediterranean environment.

Centranthus ruber has achieved optimal growth and cover in southern Tuscany (Benvenuti & Bacci, 2010). Good performance has been observed in Greece for two species of *Helicrhysum* independently of substrate depth or irrigation (Papafotiou et al., 2013). *Thymus serpyllum* reached 85% cover a few months after planting in a

Mediterranean environment with an 8 cm deep substrate (Provenzano et al., 2010).

Helichrysum stoechas and *Thymus serpyllum* were cited as being appropriate species for Mediterranean green roofs in a study by Caneva et al. (2013).

The species that thrived in the final part of our groundcover trial did, however, display varied performances in cover and were influenced to a greater extent by seasonal stresses during the Mediterranean summers and winters. If, therefore, we wish to make a long-term plan for a green roof we should be mindful of the variability described above and the reduction in species which was observed, as well as being aware that the eighteen months of this study cannot be considered sufficient. On this subject, Rowe et al. (2012) conducted a study lasting seven years of 25 Crassulaceae species cultivated on a green roof in Michigan, and concluded that the long-term survival of stress-tolerant species often depends on the depth of the soil; plants which initially survive can later experience a reduced cover or completely disappear due to competition, climate variations, and other causes.

The importance of flowering is not only due to its aesthetic appeal, but also to the fact that it attracts insects. Our study provides precise indications on how to achieve prolonged flowering in certain species in conditions of minimal or no irrigation. Brennesein (2005) showed that a vegetation composed of *Sedum* attracted only half the number of bees that were attracted by green roofs cultivated with multiple forms of vegetation, due to a shorter flowering period which made it less useful as a provider of food. In a study by Benvenuti and Bacci (2010), eighteen of the twenty species studied in a mediterranean environment flower principally in June, and half of these species also flowered briefly in autumn.

Flowering is one of the elements that defines diversity in a green roof. Biodiversity in green roofs can, apart from flowering, be determined by the way the plants respond to heterogeneous microhabitats resulting from the site-specific microclimate (Timberlake et al., 2013).

In our study, irrigation did not seem to have any particular influence on vegetation diversity, while a larger difference was observed when comparing different life forms (groundcover and subshrubs). If we compare the development of vegetation diversity, results from the Shannon Wiener index are higher for the subshrub species than for the groundcover species. Most diversity was due to the subshrub species' slightly more complex structure and to the higher presence of colonizing species. This is facilitated by the lower surface cover rate of subshrub species which favoured germination and survival of colonising species. In the subshrubs trial a higher presence of colonising species was observed, and this did not seem to change in response to different irrigation treatments, whereas abundance did vary according to the amount of water received. Many colonising species did not achieve a sufficient presence to be judged for their aesthetic or functional characteristics, and the results tell us that it is not always possible to rely on spontaneous colonisation of green roofs to increase cover and biodiversity.

The reduction of species in the green roofs over time and the danger of seeing the development of low diversity with a small number of dominant species has already been observed (Dunnett et al., 2008; Nagase & Dunnett, 2010). For this reason it is important to include green roofs in a network of urban ecological connectivity, and organise a plan of agronomic management with removal and substitution of species, and the preparation of microhabitats on green roofs (Köhler, 2006).

5. Conclusions

The results of this study suggest that green roofs in the Mediterranean area are viable, although longer study periods will be necessary in order to better understand how the vegetation we have used behaves over time. Our initial findings proved that there are species which can be used in that they achieve good results in the difficult environment of Mediterranean green roofs. Different irrigation treatments resulted in differences between irrigated plants and non irrigated plants, demonstrating that a minimum level of irrigation is necessary. Both trials saw a simplification of the initial design due to a reduction in species and an increase in the abundance of the surviving species. Structural differences between the vegetation of the two trials influenced the results of the study principally in terms of diversity and the ability to host colonising species. The level of colonisation in the groundcover trial was lower than that in the subshrub trial. Aesthetic considerations which took into account parameters of cover and flowering revealed good flowering rates in those species which were present. Variations in cover were observed especially with regard to the groundcover plants, which were more affected by the seasonal stresses typical of the Mediterranean climate.

The main risk could be that of having a green roof with a small number of species and minimal diversity in vegetation and aesthetic characteristics. This problem can be overcome with a small amount of maintenance by replacing some species over time.

The two trials and their different irrigation treatments have, throughout the duration of the study, shown a reduction in the number of species and, consequently, a reduction in flowering and diversity performance.

Acknowledgements

We would like to thank the Spanish government for their economic contributions received through the MINECO, IMPACTO, and CUMED projects.

We are also grateful for the technical support given in the field and the laboratory by Marc Ferrer, Laia Serra, Cristian Morales, Beatriz Grau, and Inma Funes, of the IRTA.

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