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An Experimental Study in Simulated Greenroof in Mediterranean Climate

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Abstract

The use of green roofs in the Mediterranean area is becoming more widespread. Use of the species which are most commonly used across the world can be limited by the specific conditions of the Mediterranean climate. An experimental green roof simulation tested the performance of 12 species divided into three groups according to growth form (ground cover, sub-shrub, rhizomatous-herbaceous). Different irrigation criteria were applied to each group: in two sections potential evapotranspiration (ET0) levels of 20% and 40% were applied, while the third section was rainfed. Mortality, green coverage, blooming and final biomass were measured.

The amount of water received and the low winter temperatures affected plant mortality. Significant differences in coverage were observed when comparing the rainfed section with the two irrigated areas. Ground cover plants in the irrigated sections achieved the best results in terms of coverage. Significant differences in biomass were observed only when comparing the irrigated plots with the rainfed plot. The influence of different irrigation protocols on flowering was observed in five species only.

The growth form groups responded in different ways to drought stress: rhizomatous-herbaceous developed slowly and consistently; ground cover developed quickly and relied more on the water supply; sub-shrubs showed lower resistance to drought stress under the present experimental conditions. Of the 12 plants tested for green-roof adaptation in a Mediterranean climate, those which performed best were: *Centranthus ruber* (L.) DC., *Santolina rosmarinifolia* L., *Helichrysum stoechas* (L.) Moench, *Iris lutescens* Lam..

Keywords: green roofs, drought stress, green coverage, mortality, flowering

1. Introduction

The remarkable growth of green roofing in Central and Northern Europe in recent years has not been followed by similar developments in nearby Mediterranean countries. Green roof experiments first took place in Germany in 1950, and other countries followed during the 1970s (Köhler, 2006). In 1982, the German Landscape Research, Development and Construction Society (FLL) published regulatory guidelines for green roofing (FLL, 2008). Many technical aspects of the issue have subsequently been investigated, with the aim of improving the efficiency of these systems with designs for lighter and safer materials and for reduced building costs. At the same time, urban ecology studies have looked at the impact of green roofs in terms of urban biodiversity (Lundholm, 2006; Bass, 2009; Lundholm & Peck, 2008; Oberndorfer et al., 2007), energy consumption (Andersson, 2006; Carter & Butler, 2008; Abram, 2011; Spala et al., 2008) and the psychological and social impact on individuals and small communities (Samangooei, 2006; So-Young et al., 2008). Over the past few years the use of green roofs has spread to Italy and Spain and other areas with continental and atlantic climates, but only very recently have green roofs begun to spread to Mediterranean coastal areas (Abram, 2006; Briz Escribano, 2004; Neila et al., 2008; Damas et al., 2010).

The genus *Sedum* represents the most widely used plant species in Mediterranean green roofs across the world. The species of this genus do perform well in terms of survival rate, but they can lack homogeneity of coverage, and have low growth rates and poor biodiversity. Studies have shown that a combination of different species results in improved resilience under stress conditions when compared to mono-species cultivations (Gedge & Kadas, 2005; Lundholm et al., 2010; Nagase & Dunnet, 2010; Bretzel et al., 2011).

Effectively combining different species in extensive Mediterranean green roofs is not an easy task. They should be selected for adaptability to the Mediterranean bioclimate as well as to urban environments, and to environmental conditions specific to green roofs (drought, poor nutrients, high temperature stress) (Caneva et al., 2013; Papafotiou et al., 2013). The species should also have low allergenicity, attract insects and birds, and display ornamental and aesthetic characteristics throughout the seasons (Benvenuti & Bacci, 2010; Provenzano et al., 2010; Brenneisen, 2006).

The urban planners of many cities integrate green roofs into the design of their ecological corridor projects, since they represent an effective method with which to extend green surface areas and increase biodiversity (Agencia de Ecología Urbana de Barcelona, 2010; Ajuntament de Barcelona, 2010; Carter & Butler, 2008; Damas et al., 2010; Lundholm & Peck, 2008). The aim of this study is to analyse the ecological behaviour of twelve plant species, which have been grouped into three different categories by taking into account their growth patterns and evaluating their performance under three different irrigation protocols (two protocols applying minimum watering and one with none) in a Mediterranean environment.

2. Materials and Methods

2.1 Study Site

The trials were carried out in Caldes de Montbui (205 m.a.s.l.) (41°63′N 2°16′E) - 30 km from Barcelona (Spain), where the Catalan mountains meet the Mediterranean coast. During the trial period (June 2009-May 2010) average monthly temperatures were between 6.1 °C and 25.1 °C. Average monthly rainfall was between 5.2 mm and 125.2 mm, potential evapotranspiration (ET0) ranged from 20.4 mm to 139.7 mm. High ET0 values were recorded during summer when rainfall was scarce. In June, ET0 reached 135.3 mm with precipitation up to 10.7 mm. In July maximum ET0 was 139.7 mm, with maximum precipitation at 10.7 mm. In August it only rained once, for a total of 27.4 mm, and ET0 reached 131 mm. Between June 2009 and May 2010 a total of 640 mm precipitation and 925 mm ET0 were recorded. Unusually, temperature values in December 2009 and March 2010 fell below 0 ºC, reaching -8 ºC and damaging some species while destroying others. Evapotranspiration values (for the calculation of irrigation patterns) and all other climate data was provided by the Caldes de Montbui weather station, located 150 m from the site of the experiment. Table 1 shows climate data related to the trial period along with a summary of the period between 1991 and 2010.

Table 1. Climatic monthly averages and absolute data* during the trial period (June 2009 - May 2010) and during the twenty year period from 1991 to 2010 (historic monthly climate data*)

Monthly data		Temp. (ºC)			Absolute Temp. (ºC)		Rainfall (mm)	ETO (mm)
		Mean	Max	Min	Max	Min		
Trial period	JUN 09	22.4	29.2	15.6	35	11.8	10.7	135.3
Historic (1991–2010)	JUN	21.0	27.3	14.7	33.8	9.1	44.6	124.9
Trial period	JUL 09	24.2	30.3	17.9	37.2	11.4	11.6	139.7
Historic (1991–2010)	JUL	23.5	29.7	17.2	35.4	11.5	24.7	130.5
Trial period	AUG 09	25.0	31.8	19.0	37.4	16.8	27.4	131.0
Historic (1991–2010)	AUG	22.4	28.2	16.8	33.6	11.0	50.7	120.7
Trial period	SEP 09	20.2	26.5	14.8	30	10.9	103.4	85.5
Historic (1991–2010)	SEP	18.9	24.6	13.8	31.2	7.7	89.1	77.3
Trial period	OCT 09	16.5	23.1	11.2	29.3	3.6	72.2	62.6
Historic (1991–2010)	OCT	15.7	21.5	10.9	27.7	3.7	81.9	53.1
Trial period	NOV 09	11.7	18.4	6.6	25	2	5.2	34.0
Historic (1991–2010)	NOV	10.1	16.4	5.0	22.3	-1.2	39.9	25.9
Trial period	DEC 09	7.4	13.0	2.8	19.2	-7.9	47.5	20.4
Historic (1991–2010)	DEC	7.2	13.4	2.4	19.1	-3.4	52.2	16.5
Trial period	JAN 10	6.2	10.8	2.5	16.5	-3.1	59	24.5
Historic (1991–2010)	JAN	6.7	13.5	1.4	19.6	- 4.0	40.4	22.3
Trial period	FEB 10	7.0	12.4	1.9	18	-5.9	89.5	36.6
Historic (1991–2010)	FEB	7.7	14.7	1.9	20.0	- 2.8	29.2	31.3
Trial period	MAR 10	8.8	14.7	3.4	20.9	-4.4	66	66.4
Historic (1991–2010)	MAR	10.5	17.2	4.4	24.4	-1.2	33.0	58.2
Trial period	APR 10	12.9	19.4	7.0	25.6	3.6	32.8	86.3
Historic (1991–2010)	APR	12.8	19.3	6.6	25.8	1.3	50.0	79.1
Trial period	MAY 10	15.3	21.2	9.6	30.1	4.1	125.2	106.9
Historic (1991–2010)	MAY	16.7	22.8	10.6	29.8	4.6	63.6	112.9

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

2.2 Simulation of a Green Roof System

The conditions found on extensive green roofs were replicated by constructing walled containers with prefabricated concrete panels. The other materials used were produced by ZinCo®: the container was covered with a synthetic water-retentive polypropylene SSM45 protection mat, having a water-retention capacity of approximately 5 m^{-2}. A drainage and water storage sheet made of recycled polyethylene Floradrain FD25-E was placed over the polypropylene sheet, having a volume of approximately 10 m^{-2}. The resulting structure was then covered with a polypropylene geo-textile, followed by a substrate of Floral Zincoterra. The substrate thickness was 11 ± 1 cm and the total system thickness was approximately 15 cm. The ZinCo Floral substrate was composed mainly of brick fragments with organic matter making up approximately 10% of its content (Zinco, 2010). Apparent density of the substrate was 90%, with a total porosity of 66%, pH values ranged between 7.95 and 8.08 and electrical conductivity values ranged from 158.4 to 194.2 µS/cm (microSiemens/cm). Porosity and density levels were calculated in the laboratory using samples from the substrate, while pH and electrical conductivity were measured every three months using a laboratory pH meter.

2.3 Plants

Twelve species were selected according to their ecological and structural characteristics (see Table 2) and their availability in commercial nurseries. The flora of different environments was taken into consideration, including rocky environments, dunes, and dry coastal areas. The flora of conglomerate soils were also examined, as well as surfaces without an edaphic layer such as walls and cliffs (Caneva et al., 2013). Species were classified according to three different growth-forms: ground cover, sub-shrub, and rhizomatous-herbaceous. Such a classification is mainly related to the morphological behaviour of plants growing in a Mediterranean environment, although some species can display different features in different environments due to phenotypic plasticity.

Table 2. Selected species: ecological and structural information

Species	Botanic family	Chorotype	Environment	Growth form
Armeria maritima (P. Mill.) Willd.	Plumbaginaceae	Sub-cosmopolita	Coastal areas, dry environment, sandy soils, marshland	Rhizomatous-herbaceous
Asteriscus maritimus (L.) Less.	Compositae	W. Medit.	Rocky coastal Sandy like soils	Sub-shrub
Centranthus ruber (L.) DC.	Valerianaceae	Steno Medit.	Calcareous and rocky soils	Sub-shrub
Dymondia margaretae Compton	Asteraceae	South Africa	Sandy coastal soils	Ground cover
Drosanthemum floribundum (Haw.) Schwantes	Aizoaceae	South Africa	Cultivated and sub-spontaneous in Mediterranean area	Sub-shrub
Frankenia laevis L.	Frankeniaceae	Steno Medit.-Central Asia South Africa	Sandy coastal soils and marshland	Ground cover
Helichrysum stoechas (L.) Moench	Compositae	W. Medit.	Sandy, rocky dry soils	Sub-shrub
Iris lutescens Lam.	Iridaceae	NW-Steno-Medit.	Dry and rocky fields	Rhizomatous-herbaceous
Limonium virgatum (Willd.) Fourr.	Plumbaginaceae	Euri-Medit.	Costal retro dunes and salty cliffs	Rhizomatous-herbaceous
Lotus creticus L.	Leguminosae	Steno Medit.	Coastal sandy soils and dune systems environments	Sub-shrub
Santolina rosmarinifolia L.	Compositae	W. Medit. North Africa	Dry rocky, sandy, conglomerate like soils	Sub-shrub
*Thymus serpyllum** L.	Labiatae	Euri-Medit.	Arid grasslands, rocky soils and mesophytic forest borders	Sub-shrub/ground cover

Note. *Differential behavior due to phenotypic plasticity.

2.4 Experimental Design and Irrigation

The experimental design consisted of a split-plot: the main influencing factor was irrigation, with the application of three different irrigation protocols; the second influencing factor was plant species; twelve different species were included in the experiment. Three plots were planted for each irrigation protocol for a total of nine plots. Each of the nine main plots had a surface area of 12 m^2 and was divided into twelve sub-plots of 1 m^2 each. Nine plants of a single species were planted in each sub-plot resulting in a density of nine plants per square meter. The placement of the twelve species was the same for every plot in each irrigation protocol. Three different irrigation protocols were used: rain fed (no use of artificial irrigation, 0% ET0); replenishment of 20% of water lost to potential evapotranspiration (20% ET0); and replenishment of 40% of the same (40% ET0). The quantity of water supplied was calculated on a weekly basis, taking into account the previous week's data and subtracting the total amount of precipitation from the total value of ET0 (evapotranspiration minus rainfall). The resulting amount of water was distributed evenly throughout the week. The water distribution system was composed of drip emitting tubes placed on the surface with a diameter of 16 mm, and a 30 cm space between tubes, with a flow rate of 22.8 litres/m^2/hour. Over the whole period of the trial, 216 litres/m^2 of water were supplied to the 40 % ET0 sub-plots and 108 litres/m^2 to the 20% ET0 sub-plot; the average weekly values were, respectively, 4.9 and 2.5 litres/m^2 for the two irrigation protocols. The water supplied during the hottest months (from June to September) was 184 litres for the 40% ET0 irrigation protocol and 92 litres for the 20% ET0 protocol, equivalent to 85% of the total water supplied throughout the year.

2.5 Green Roof Performance and Measures

The following parameters were measured: mortality, coverage, timing, duration and percentage of flowering, and hypogeal and epigeal biomass. The results for each species were analysed according to their functional group and to the irrigation protocol assigned to them. The survival rate of the plants was measured each month; frequency and duration of flowering were recorded every fifteen days. Plants lacking leaves and living branches were considered dead and left *in situ*. Flowering was recorded throughout the trial period. In order to evaluate the entire flowering period of a plant the duration and number of flowering branches were recorded. The number of flowering branches was also recorded as a percentage of the total number of branches on a single plant. With regard to coverage, the experimental system was photographed every two months, from a height of 2.5 m with a Nikon EOS 500 camera using Nikon EOS specific software. Photographs were taken around midday (11 am - 2 pm) in order to reduce the effect of shadows. The camera was placed on a tripod equipped with a horizontal extendable arm. All photographs were taken from the same distance and height, and the same image and camera settings were used. Images were then processed with the Greenpix software (developed by the Institut de Recerca i Tecnologia Agroalimentàries - IRTA), for the analysis of digital images (Casadesús et al., 2005, 2007). A Hue range of 0 to 180 was used, making it possible to identify the number of yellow, brown and green pixels, and to calculate the percentage of each color portion in relation to the total image pixels, and to transform the pixels into cm^2 for an evaluation of total cover (green, yellow and brown). With regard to the plant growth parameter, only the green surface corresponding to pixels within the 60-180 Hue range was taken into account. The evaluation of biomass was carried out by sorting the different species according to location and to irrigation protocol. All plants were then carefully separated from the earth In some cases portions of roots were sifted out from the substrate. Finally, the epigeal parts (leaves and stalk) were separated from the roots. The roots were rinsed thoroughly with water, and all plants were placed in a paper bag allowing permeation of air and humidity. All plant material was then dried in an oven for a period of seven days at 65 ºC before being weighed.

2.6 Statistical Analysis

An experiment was designed to measure the following factors: irrigation, species, and sampling. In order to study the spread of the coverage area for each species, the ANOVA mixed models statistical analysis was applied using the sampling and irrigation factors as fixed data, and the block as a variable factor; three levels were set for the irrigation factor, eight for the sampling factor, and three for the block factor. To determine significant outcome differences between the irrigation protocols and the sampling schedule, a post hoc test was applied using Tukey adjustments. The same analysis was carried out by grouping the species according to their growth form. Biomass analysis for each species was carried out using ANOVA mixed models, setting a fixed variable (irrigation protocol) and a random variable (block). The overall analysis was conducted using version 9.2 of the SAS software. For each irrigation protocol plot, mean biomass and mean coverage, both according to growth form, were compared using the Tukey Kramer HSD test and version 10 of the JMP software.

3. Results

3.1 Plant Mortality

Average mortality results of each growth form are reported in Table 3: mortality rates of all species, categorised by irrigation protocol, are shown in Figure 1. It can be seen that the mortality rate of *Asteriscus maritimus*, *Drosanthemum floribundum* and *Lotus creticus* was above 81% in winter, regardless of the irrigation protocol applied. The remaining species to which water was supplied artificially resulted in a mortality rate ranging from 0% to 38%, whereas the species in the rain fed group showed mixed results: *Asteriscus maritimus*, *Drosanthemum floribundum*, *Lotus creticus* and *Dymondia margaretae* had an almost 100% mortality rate; *Frankenia laevis* and *Limonium virgatum* had a mortality rate of 70% and 74% respectively; *Thymus serpyllum* 48%; *Helichrysum stoechas* 37%; the mortality rates of *Armeria maritima*, *Centranthus ruber*, *Iris lutescens* and *Santolina rosmarinifolia* were between 14% and 18%.

3.2 Coverage

Coverage values of each species were categorised according to irrigation protocol and to growth form. The results of each group's coverage performance throughout the trial are shown in Table 4. Table 5 shows total averages and significant differences: all growth form groups displayed significant differences in terms of coverage when comparing the irrigated plots with the rain fed plot. Irrigated plants reached greater coverage in May and November; the lowest values were recorded in March. The results of each species were as follows (Figure 2): *Armeria maritima*, *Iris lutescens* and *Santolina rosmarinifolia* showed steady growth without seasonal variation. *Thymus serpyllum*, *Frankenia laevis*, *Limonium virgatum* and *Centranthus ruber* are the species that performed best in the irrigated protocols when the trial was completed, despite showing seasonal variations. The worst final results, irrespective of irrigation protocol, were recorded for *Asteriscus maritimus*, *Lotus creticus* and *Drosanthemum floribundum*. In the rain fed protocol *Centranthus ruber*, *Helichrysum stoechas* and *Limonium virgatum* showed the best results.

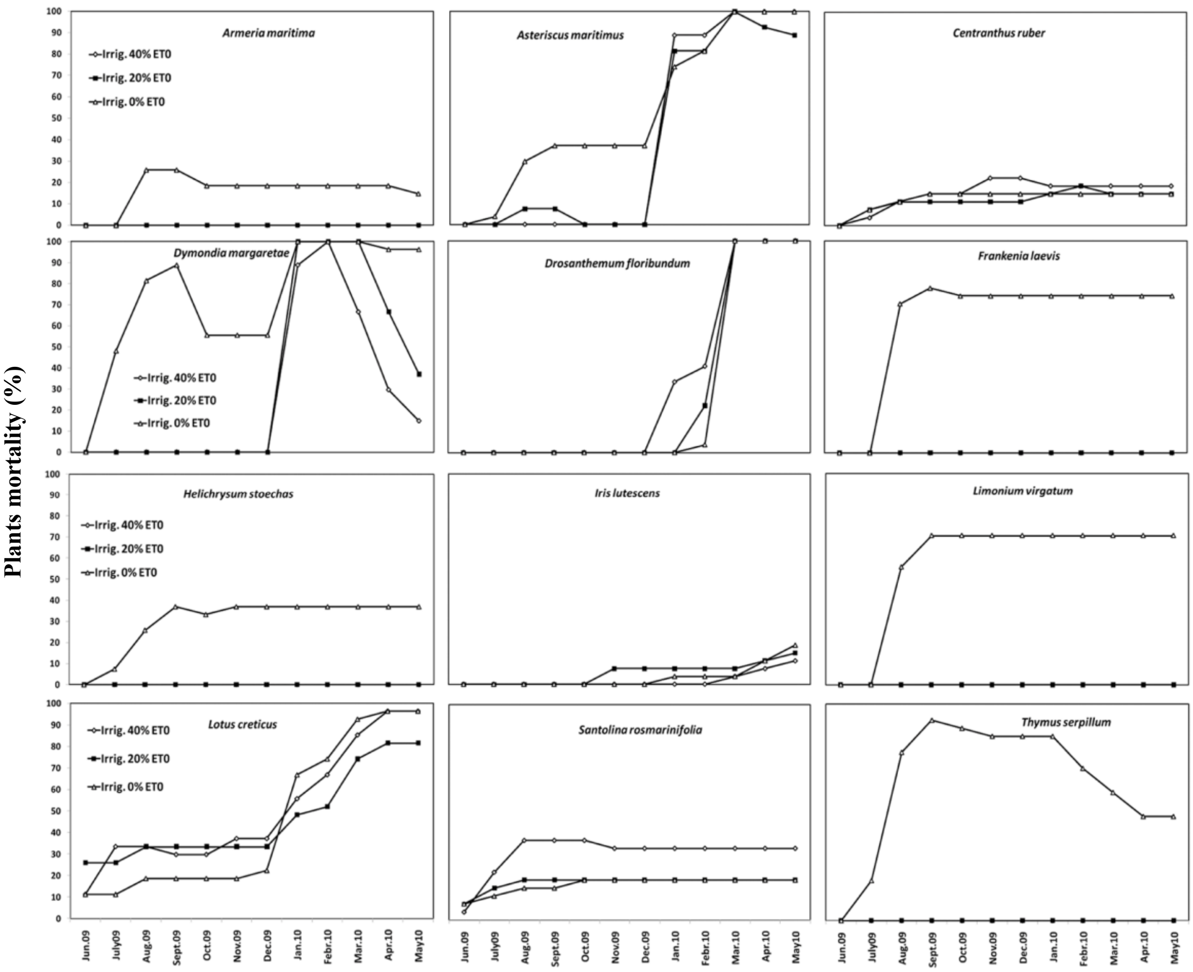

Figure 1. Mortality rate of species from June 2009 to May 2010 according to rain fed (0% ET0), 20% ET0 and 40% ET0 irrigation protocols

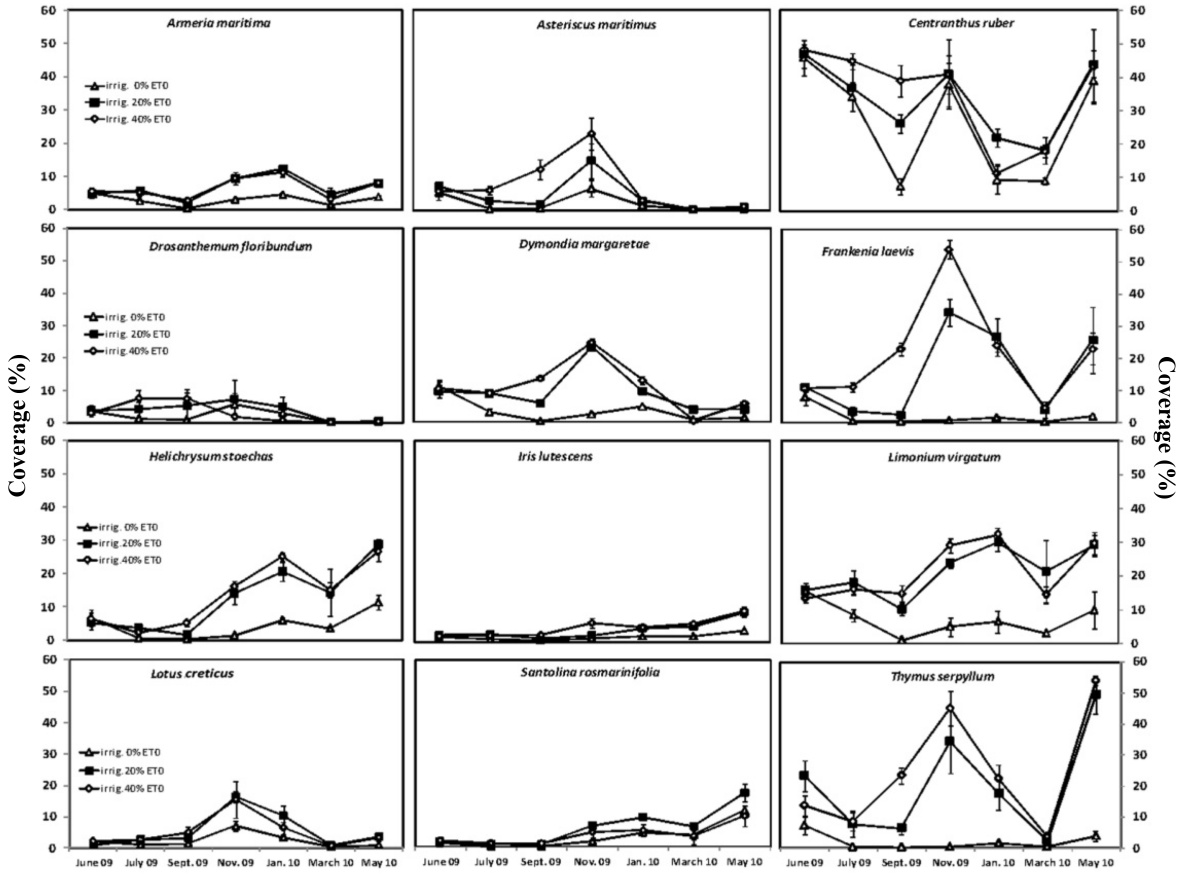

Figure 2. Green cover from June 2009 to May 2010 according to the different irrigation protocols 0%, 20%, and 40% of ET0. Final values are the result of 3 mean values ± standard error

Table 3. Summary of plant mortality by percentage (± standard error) for three irrigation treatments 0%, 20%, 40% ET0 (average figures for all values under the same irrigation protocol) and for three life-form groups (sub-shrubs, ground cover, rhizomatous-herbaceous) categorized by irrigation protocol 0%, 20%, 40% ET0

% Plants Mortality						
Date	***Irrigation 0% ET0***	***Irrigation 20% ET0***	***Irrigation 40% ET0***	***Sub-shrubs irrigation 0% ET0***	***Sub-shrubs irrigation 20% ET0***	***Sub-shrubs irrigation 40% ET0***
June 2009	1.54±1.06	2.78±2.19	1.23±0.95	2.65±1.75	4.76±3.68	2.12±1.59
July 2009	8.95±3.96	4.01±2.39	4.94±3.17	8.47±2.24	6.88±3.83	8.47±5.16
Aug. 2009	34.26±8.51	5.86±3.04	6.79±3.94	25.40±9.47	10.05±4.69	11.64±6.28
Sept. 2009	39.81±9.79	5.86±3.04	6.79±3.81	30.69±11.45	10.05±4.69	11.64±6.02
Oct. 2009	35.80±8.61	5.25±3.07	6.79±3.81	30.16±10.83	8.99±4.91	11.64±6.02
Nov. 2009	35.80±8.44	5.86±3.04	7.72±4.14	30.16±10.40	8.99±4.91	13.23±6.46
Dec. 2009	36.11±8.38	5.86±3.04	7.72±4.14	30.69±10.31	8.99±4.91	13.23±6.46
Jan. 2010	46.91±10.12	22.53±10.11	26.54±9.92	42.33±12.52	23.28±11.68	32.80±11.97
Feb. 2010	47.22±9.95	25.00±9.95	29.01±10.79	42.86±12.12	27.51±11.14	35.45±12.60
Mar. 2010	57.41±10.75	34.57±12.84	33.95±12.10	60.32±14.27	43.92±17.29	48.15±17.24
April 2010	57.10±10.51	32.10±11.67	32.10±12.09	59.26±14.59	43.92±17.10	49.74±17.87
May 2010	57.41±10.39	29.63±11.06	31.17±12.13	59.26±14.59	43.39±16.85	49.74±17.87
Date	***Ground cover irrigation 0% ET0***	***Ground cover irrigation 20% ET0***	***Ground cover irrigation 40% ET0***	***Rhizomatou-herbaceous irrigation 0% ET0***	***Rhizomatou-herbaceous irrigation 20% ET0***	***Rhizomatous-herbaceous irrigation 40% ET0***
June 2009	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
July 2009	22.22±14.02	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Aug. 2009	76.54±3.27	0.00±0.00	0.00±0.00	27.16±16.05	0.00±0.00	0.00±0.00
Sept. 2009	86.42±4.45	0.00±0.00	0.00±0.00	32.10±20.55	0.00±0.00	0.00±0.00
Oct. 2009	72.84±9.64	0.00±0.00	0.00±0.00	29.63±21.06	0.00±0.00	0.00±0.00
Nov. 2009	71.60±8.64	0.00±0.00	0.00±0.00	29.63±21.06	2.47±2.47	0.00±0.00
Dec. 2009	71.60±8.64	0.00±0.00	0.00±0.00	29.63±21.06	2.47±2.47	0.00±0.00
Jan. 2010	86.42±7.51	33.33±33.33	29.63±29.63	30.86±20.21	2.47±2.47	0.00±0.00
Feb. 2010	81.48±9.32	33.33±33.33	33.33±33.33	30.86±20.21	2.47±2.47	0.00±0.00
Mar. 2010	77.78±11.91	33.33±33.33	22.22±22.22	30.86±20.21	2.47±2.47	1.23±1.23
April 2010	72.84±13.91	22.22±22.22	9.88±9.88	33.33±18.64	3.70±3.70	2.47±2.47
May 2010	72.84±13.91	12.35±12.35	4.94±4.94	34.57±17.93	4.94±4.94	3.70±3.70

Table 4. Summary of coverage by percentage (± standard error) for three irrigation protocols 0%, 20%, 40% ET0 (average figure for all values of the same treatment) and three life-form groups for each irrigation protocol 0%, 20%, 40% ET0 (sub-shrubs, ground cover, rhizomatous- herbaceous)

Coverage %						
Date	***Irrigation 0% ET0***	***Irrigation 20% ET0***	***Irrigation 40% ET0***	***Sub-shrubs irrigation 0% ET0***	***Sub-shrubs irrigation 20% ET0***	***Sub-shrubs irrigation 40% ET0***
June 09	10.42±3.52	12.12±3.72	11.35±3.64	10.91±0.87	13.57±6.27	12.38±6.16
July 09	4.72±2.76	8.93±2.91	10.66±3.39	5.55±4.76	8.78±4.71	11.16±5.73
Sept. 09	1.25±0.57	6.07±2.03	14.03±3.36	1.72±0.96	6.73±3.31	14.60±5.11
Nov. 09	6.72±2.95	21.49±3.78	25.65±5.08	9.45±4.90	21.26±4.72	23.63±6.55
Jan. 10	4.73±0.77	15.58±2.38	14.66±2.86	4.80±1.10	13.70±2.70	11.43±3.42
Mar. 10	2.43±0.80	7.59±2.06	6.30±1.82	2.94±1.34	6.78±2.85	6.28±2.76
May 10	8.30±3.22	20.06±4.80	19.27±4.84	10.87±5.38	22.40±7.76	20.86±8.04
Date	***Ground cover irrigation 0% ET0***	***Ground cover irrigation 20% ET0***	***Ground cover irrigation 40% ET0***	***Rhizomatous-herbaceous irrigation 0% ET0***	***Rhizomatous-herbaceous irrigation 20% ET0***	***Rhizomatous-herbaceous irrigation 40% ET0***
June 09	11.10±3.51	16.58±3.57	13.83±1.92	4.55±1.10	16.25±7.04	16.81±7.82
July 09	2.02±1.55	8.72±3.32	11.48±1.81	4.05±2.17	9.09±4.51	8.01±4.02
Sept. 09	0.43±0.08	6.13±2.11	22.92±0.27	2.39±0.48	11.11±5.14	8.79±3.25
Nov. 09	1.76±1.14	35.69±1.48	46.58±3.82	6.41±1.81	17.27±6.23	17.63±6.32
Jan. 10	3.71±2.10	19.97±3.36	22.63±0.72	3.23±0.97	12.09±6.13	15.90±6.56
Mar. 10	0.64±0.28	4.17±1.21	2.99±1.17	7.54±4.03	7.94±4.01	7.24±3.18
May 10	2.72±0.60	27.15±2.39	28.75±13.17	0.69±0.17	4.56±2.78	6.96±3.92

Table 5. Summary of percentage of coverage for three irrigation protocols 0%, 20%, 40% ET0 (average figure for all values of the same treatment) and three life-form groups for each irrigation protocol 0%, 20%, 40% ET0 (sub-shrubs, ground cover, rhizomatous-herbaceous). Average figures not associated with the same letter are significantly different at $p < 0.05$ (TEST TUKEY KRAMER HSD)

Irrigation			***Sub-shrubs***			***Ground cover***			***Rhizomatous-herbaceous***		
0% ET0	4.64	**B**	***0% ET0***	6.60	**B**	***0% ET0***	3.19	**B**	***0% ET0***	4.12	**B**
20% ET0	13.80	**A**	***20% ET0***	13.31	**A**	***20% ET0***	16.91	**A**	***20% ET0***	11.18	**A**
40% ET0	15.75	**A**	***40% ET0***	14.33	**A**	***40% ET0***	21.30	**A**	***40% ET0***	11.62	**A**

3.3 Flowering

Most species flowered during the Summer of 2009 and Spring of 2010 (see Table 6). The only species that presented differences in the duration of its flowering period between one irrigated plot and another was *Thymus serpyllum,* which flowered until October in the 40% ET0 protocol plots, two months longer than the plants in the 20% ET0 protocol plots; and *Asteriscus maritimus* which flowered an additional month when being watered with the 40% ET0 system compared to plants in the 20% ET0 protocol plots. *Lotus creticus* and *Santolina rosmarinifolia* did not flower at all, whereas *Frankenia laevis,* (butonly the plants in the 20% ET0 protocol plots)presented limited flowering in May. *Dymondia margaretae* flowered only in August. *Asteriscus maritimus,Centranthus ruber, Helichrysum stoechas, Limonium virgatum* and *Thymus serpyllum* presented limited flowering in terms of time and quantity in the rain fed plots when compared to the plants in the irrigated plots.

Table 6. Flowering periods of the trial species for three different irrigation protocols: 0% ET0, 20% ET0 and 40% ET0

Plants species	Irrigation	Flowering periods											
		June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Armeria maritima	0% ET0		= 50%									> 50%	> 50%
	20% ET0		= 50%									> 50%	> 50%
	40% ET0		= 50%									> 50%	> 50%
Asteriscus maritimus	0% ET0		> 50%	> 50%									
	20% ET0		> 50%	> 50%		= 50%							
	40% ET0		= 50%	= 50%	< 50%	= 50%							
Centranthus ruber	0% ET0		= 50%	> 50%								= 50%	> 50%
	20% ET0		= 50%	> 50%	> 50%							= 50%	> 50%
	40% ET0		= 50%	> 50%	> 50%							= 50%	> 50%
Drosanthemum floribundum	0% ET0	= 50%											
	20% ET0	= 50%											
	40% ET0	= 50%											
Dymondia margaretae	0% ET0			= 50%									
	20% ET0			= 50%									
	40% ET0			= 50%									
Frankenia laevis	0% ET0												
	20% ET0												= 50%
	40% ET0												
Helichrysum stoechas	0% ET0		= 50%										
	20% ET0		= 50%	= 50%									
	40% ET0		= 50%	= 50%									
Iris lutescens	0% ET0										— / = 50%	> 50%	
	20% ET0										— / > 50%	> 50%	
	40% ET0										— / > 50%	> 50%	
Limonium virgatum	0% ET0		= 50%	> 50%									
	20% ET0		= 50%	> 50%	> 50%								
	40% ET0		= 50%	> 50%	> 50%								
Lotus creticus	0% ET0												
	20% ET0												
	40% ET0												
Santolina rosmarinifolia	0% ET0												
	20% ET0												
	40% ET0												
Thymus serpyllum	0% ET0			> 50%	< 50%								
	20% ET0		= 50%	> 50%									
	40% ET0		= 50%	> 50%		= 50%							

Note. Quantity of bloomed branches: (light grey) < 50%; (grey) = 50%; (dark grey) > 50%.

3.4 Biomass

In all growth forms, the biomass of the upper portion was greater than that of the root system; all groups presented significant differences in biomass production when comparing the irrigated plots to the rain fed plots, with the exception of the roots of rhizomatous-herbaceous. No group displayed significant differences in biomass production between the two irrigation protocols (20% and 40% ET0) (Table 7). Table 8 shows the average biomass values of each species and its portions (shoot system, root system, and total biomass) and the ratio between root system and shoot system for each irrigation protocol. Only nine out of the twelve species were used for this analysis, because the remaining three (*Asteriscus maritimus*, *Drosanthemum floribundum*, *Lotus creticus*) had an insufficient biomass for sampling. Sampling of *Dymondia margaretae* was performed only for the plants in the irrigated plots, because all plants in the rain fed plots died. Of the nine species recorded, five (*Armeria marítima*, *Frankenia laevis*, *Helichrysum stoechas*, *Iris lutescens* and *Thymus serpyllum*) displayed significant differences between shoot system and total biomass. *Centranthus ruber*, *Limonium virgatum* and *Santolina rosmarinifolia* did not display any significant differences between irrigation protocols in terms of epigeal development. Four species developed a significantly greater root system biomass for the irrigated plants than for the rain fed plants: *Armeria maritima*, *Dymondia margaretae*, *Frankenia laevis*, *Helichrysum stoechas* and *Thymus serpyllum*. For *Limonium virgatum,* there was a significant difference between root system biomass values in the rain fed and 20% ET0 protocol plots and those in the 40% ET0 protocol plots.

Table 7. Average for g (± standard error) of the different fragments and total dry biomass (g) of the plants under three irrigation protocols 0%, 20%, 40% ET0 (average figure for all values of the same treatment), and of the three life-form groups for each irrigation protocol 0%, 20%, 40% ET0 (sub-shrubs, ground cover, rhizomatous-herbaceous). Average figures not associated with the same letter are significantly different ($p < 0.05$) (TEST TUKEY KRAMER HSD)

BIOMASS				
Irrigation				
	Nº	Shoot system	Root system	Total
0% ET0	138	24.11± 2.30 b	6.61± 0.62 b	30.72± 2.55 b
20% ET0	222	39.50± 1.82 a	8.94± 0.49 a	48.36± 2.01 a
40% ET0	219	40.79± 1.83 a	8.57± 0.49 a	49.37± 2.02 a
Sub-shrubs				
	Nº	Shoot system	Root system	Total
0% ET0	80	27.95± 2.80 b	8.12± 0.89 b	36.07± 3.51 b
20% ET0	99	45.20± 2.52 a	11.60± 0.80 a	56.68± 3.16 a
40% ET0	93	40.92± 2.60 a	10.42± 0.82 ab	51.34± 3.26 a
Ground cover				
	Nº	Shoot system	Root system	Total
0% ET0	26	4.79± 4.92 b	0.71± 0.88 b	5.50± 4.76 b
20% ET0	73	29.80± 2.94 a	6.88± 0.52 a	36.69± 2.84 a
40% ET0	77	34.21± 2.86 a	7.81± 0.51 a	42.03± 2.77 a
Rhizomatous-herbaceous				
	Nº	Shoot system	Root system	Total
0% ET0	51	19.64± 3.76 b	4.96± 0.92 a	24.60± 3.75 b
20% ET0	77	37.55± 3.06 a	7.07± 0.75 a	44.53± 3.05 a
40% ET0	76	44.56± 3.08 a	6.37± 0.75 a	50.93± 3.07 a

Table 8. Average dry weight (g) of the trial species under three irrigation protocols (40% ET0, 20% ET0, and 0% ET0). Average figures not associated with the same letter are significantly different (p < 0.05)

Plants species	Irrigation	Shoot system (g)	Root system (g)	Total (g)	Root/Shoot
Armeria maritima	0% ET0	13.64 b	1.31 b	14.96 b	0.1 a
	20% ET0	26.14 a	3.04 a	29.17 a	0.1 a
	40% ET0	27.97 a	2.88 a	30.85 a	0.1 a
Centranthusruber	0% ET0	46.61 a	17.97 a	64.58 a	0.4 a
	20% ET0	56.94 a	20.05 a	76.99 a	0.4 a
	40% ET0	49.86 a	20.10 a	69.96 a	0.4 a
Dymondia margaretae	0% ET0				
	20% ET0	8.11 b	8.47 b	16.57 a	1.0 a
	40% ET0	2.83 a	13.13 a	15.96 a	4.6 a
Frankenia laevis	0% ET0	12.92 c	1.35 b	14.27 b	0.1 b
	20% ET0	46.19 b	4.91 a	51.10 a	0.1 b
	40% ET0	62.10 a	4.50 a	66.60 a	0.1 a
Helichrysu stoechas	0% ET0	29.99 b	5.40 b	35.39 b	0.2 a
	20% ET0	52.32 a	9.53 a	61.84 a	0.2 a
	40% ET0	50.36 a	8.83 a	59.19 a	0.2 a
Iris lutescens	0% ET0	12.46 b	8.88 a	21.34 b	0.7 a
	20% ET0	18.66 ab	14.37 a	33.03 ab	0.8 a
	40% ET0	26.35 a	14.08 a	40.43 a	0.5 a
Limonium virgatum	0% ET0	50.14 a	6.04 a	56.18 a	0.1 c
	20% ET0	65.25 a	5.32 a	70.56 a	0.1 b
	40% ET0	76.01 a	3.59 b	79.60 a	0.0 a
Santolina rosmarinifolia	0% ET0	29.53 a	6.44 a	35.97 a	0.2 a
	20% ET0	44.98 a	9.93 a	54.91 a	0.2 a
	40% ET0	26.85 a	6.50 a	33.35 a	0.2 a
Thymus serpyllum	0% ET0	1.79 b	0.48 b	2.27 b	0.3 a
	20% ET0	28.65 a	7.76 a	36.41 a	0.3 a
	40% ET0	33.04 a	6.60 a	39.64 a	0.2 a

4. Discussion

4.1 Mortality

Two main factors affected plant mortality: the amount of water received and the low winter temperatures. The mortality rate of all rain fed species rose during the trial. Irrigated plants experienced a higher mortality rate in January than in other months due to low temperatures.

4.2 Coverage

As shown in the literature, the growth form and morphology of a plant affect the interception of rain by the substrate as well as its thermal and hydrological characteristics (Del Barrio, 1998; Dunnett et al., 2008; Nagase & Dunnett, 2012; Mentens et al., 2005; Buccola & Spolek, 2010; Scott MacIvor et al., 2011; Olivieri et al., 2013). In this trial the sub-shrub form was shown to be affected by low temperatures more than other forms; ground cover species suffered more than others from drought; and rhizomatous-herbaceous plants were the least affected by drought and cold weather.

Green cover had two growth peaks, in autumn and spring, corresponding to typical seasonal changes in the Mediterranean climate. In these seasons the increased availability of rainwater associated with low evapotranspiration can reduce the importance of irrigation. In spring and autumn the rain fed plants (grouped by species or by growth form) extended their percentage of coverage, achieving higher growth rates than those in the irrigated plots, although they did not exceed a maximum value of 11%; a better performance may be advantageous if they are to be used in green roofs. Some species, despite low final coverage, developed slowly and constantly, showing that the speed of coverage development and the colonisation of ecological niches varies for each species; this depends mostly on stress tolerance and ecological characteristics (Benvenuti, 2014). In order to obtain greater cover with those species which displayed low development, it is advisable to use higher plant density.

Notable differences in terms of coverage arise only when comparing rain fed plots with irrigated plots (regardless of the specific irrigation protocol applied). The results of this study did not achieve the official requirements established for temperate climate countries, which require a minimum coverage of 80% of the total surface (FLL, 2008) after the initial period. Given requirements are not always applicable in a Mediterranean environment, thermal and rainfall conditions are very different in the Mediterranean area compared to Northern Europe (Van Mechelen et al., 2014). In this study, irrigated ground cover species achieved higher coverage values compared to other growth forms, this could be due to morphological difference in these plants. The development of ground cover plants was mainly horizontal and they produced root systems which allowed them to spread out and multiply; sub-shrubs developed mainly in volume. Rhizomatous-herbaceous and sub-shrubs displayed minor seasonal variations and achieved lower coverage values compared to the ground cover plants. All rain fed plots resulted in a lower percentage of coverage. In order to reach a wider coverage as quickly as possible, and to achieve ornamental heterogeneity, all three growth forms should be used, with a prevalence of ground cover plants.

4.3 Flowering

Irrigation influenced the flowering of five species. The flowering period of rain fed plants, in some cases, was delayed or ended early, and they displayed a lower percentage of flowering branches. In Mediterranean environments plants often flower in spring, and occasionally a new outbreak is expected in autumn. The evaluation of the percentage of flowering branches for each plant and of their flowering period makes it possible to analyse responses to stress conditions, but these parameters do not include the size of the plant, making it difficult to carry out a complete aesthetic evaluation. This study provides information about species which are able to produce flowers in conditions of little to no artificial watering. The results also suggest that irrigation could be required in order to obtain even minimal flowering on Mediterranean green roofs, due to the severe summer drought.

4.4 Biomass

Final average biomass values back up most of the parameters analysed: no significant difference arises between results from the two irrigation protocols. The experimental settings may have been responsible for the fact that significant differences appeared only when comparing irrigated plots with rain fed plots: it is not possible to detect a difference in outcomes between the two minimal irrigation protocols, although it is possible to compare their results with the rain fed outcome. A study carried out in a Mediterranean-Australian climatic zone obtained similar results: plants with similar irrigation protocols did not present any difference in their final biomass (Williams et al., 2010). In terms of species, five out of nine displayed significant differences in total biomass values, and four species also displayed significant differences in their root systems between irrigated and rain fed plots. The ratio between root biomass and upper portions did not present significant differences between one irrigation protocol and another, apart from two species (*Frankenia laevis* e *Limonium virgatum*), suggesting that biomass was distributed homogeneously between roots and upper parts. On the other hand, a study carried out by Farrell et al. (2013) on the possibility of using species which grow on a thin granite substrate, observed that most species responded to water shortages by increasing the supply to the roots and reduced their leaf surface area.

4.5 Species

The analysis of single species shows that *Centranthus ruber* employs a strategy that causes a reduction of the shoot system during winter and a greater vegetative growth in spring, coinciding with the season where no water was supplied although the reduced water supply in summer affected coverage, which decreased in plants receiving 20% of ET0 and in rain fed plants. Flowering also suffered a negative effect in rain fed plants, whose flowering duration was shortened by one month. A study carried out in Tuscany, Italy (Benvenuti & Bacci, 2010) using *Centranthus ruber* on an igroperlite®substrate at different depths (15 cm and 20 cm), obtained a coverage of 62% and 100% respectively. This species is well adapted to Mediterranean conditions. The high mortality rate of rain fed *Frankenia laevis*, and variations in its coverage throughout the seasons, show the high dependence of this species on irrigation. *Armeria maritima* and *Iris lutescens* developed slowly, reaching minimal coverage values which remained consistent throughout the trial. Nevertheless, their mortality rate was low, making their use in green roofs advisable: increasing the density of initial planting could compensate for reduced growth. Provenzano et al. (2010), in a study carried out in Italy, confirmed these same results for *Armeria maritima,* for which they obtained a coverage of 40% along with a low growth rate on an 8 cm deep irrigated substrate, where the ground humidity was lower than 20%. *Santolina rosmarinifolia* and *Helichrysum stoechas* showed high adaptability to the Mediterranean climate, presenting little variation in coverage and low mortality rates. The growth rate of *Santolina* rosmarinifolia was not improved by the water supply, as opposed to *Helichrysum stoechas*. Papafotiou et al. (2013) have observed that two species of *Helichrysum*, tested with limited irrigation, were found to be appropriate for mediterranean green roofs. *Thymus serpyllum*, when irrigated, reached high coverage values of about 50%. This growth performance has been confirmed by two separate studies: Provenzano et al. (2010), in a Mediterranean environment, on an 8 cm deep substrate, reported coverage of 85% some months after winter transplanting; in Japan a trial was conducted on a 10 cm deep substrate, receiving 5 litres of water every two days, the coverage increased by more than 70% between May and September, reaching a final value of 90% (Takahiro et al., 2010). In this trial, rain fed plants reached 4% coverage. Irrigated plants benefitted in terms of flowering, mortality and coverage (mainly during the summer), this species therefore seems to rely on watering. Rain fed *Dymondia margaretae* did not tolerate drought, resulting in high mortality rates in summer, whereas irrigated plants of this species did not tolerate low temperatures (their leaves dried). However, it presented good vegetative growth over the following spring. This is the only species in which the root system biomass exceeded that of the shoot system; growth was limited and flowering scarce. Mortality for *Asteriscus maritimus*, *Lotus creticus* and *Drosanthemum floribundum* was caused by low winter temperatures, regardless of the irrigation protocol – meaning that the water supplied throughout the trial did not improve resistance. Irrigated plants of the *Limonium virgatum* species had a 100% survival rate, and little variation in flowering and coverage; growth was constant throughout the trial. Rain fed plants had a reduced flowering period (one month less compared to irrigated plants). The rosette plant structure does not allow rapid extension in coverage. However, the ability to produce viable seeds, their germination, and the survival of seedlings demonstrated efficient adaptation to the Mediterranean climate.

5. Conclusion

This study shows that some species can be used with minimal irrigation for green roofs in the Mediterranean area. The results provide indications on growth form functionality: different growth form groups responded in different ways to stresses of different seasons. Rhizomatous-herbaceous developed slowly and consistently; ground cover plants developed quickly and relied more on the water supply; sub-shrubs showed lower resistance to stresses under the present experimental conditions. *Centranthus ruber*, *Santolina rosmarinifolia*, *Helichrysum stoechas* and *Iris lutescens* performed well under the experimental conditions; the performance of *Limonium virgatum*, *Armeria maritima*, *Frankenia laevis* and *Thymus serpyllum* was good, although the results are dependent on minimal irrigation (growth in *Armeria maritima* and *Iris lutescens* was slower than in other species); *Asteriscus maritimus*, *Lotus creticus*, *Drosanthemum floribundum* and *Dymondia margaretae* failed to adapt to the experimental conditions of this trial. This study is a useful tool for the selection of plants for use in Mediterranean green roofing, providing information on survival and the development of plant types and species. An appropriate mixture of all three growth forms could be an interesting subject for future investigation, especially in relation to the amount of water required.

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