



Article

# Green Roof Design Techniques to Improve Water Use under Mediterranean Conditions

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**Abstract:** Green roof typology can vary depending on buildings structure, climate conditions, substrate, and plants used. In regions with hot and dry summers, such as the Mediterranean region, irrigation plays an essential role, as the highest temperatures occur during the driest period of the year. Irrigation might reduce the heat island effect and improve the cooling of buildings during this period, however, the added cost of maintenance operations and additional energy consumption could outrun the benefits provided by the project. Moreover, in situations where water is scarce or primarily channelled to other uses (e.g., domestic, agriculture or industry) during drought occurrence, it is advisable to implement green roof projects with the lowest use of water possible. The objective of the present work is to investigate solutions to optimize water use in green roofs under Mediterranean conditions, such as those of southern Europe. Two case studies are presented for Portugal, and potential techniques to reduce irrigation requirements in green roofs were tested. These addressed the use of native plant species, including the extreme type of a non-irrigated green roof (Biocrust roof) and techniques for plant installation. Plant drought tolerance was found to be an advantage in green roofs under these climatic conditions and, for the species studied, aesthetic value could be maintained when irrigation decreased.

**Keywords:** irrigation; southern Europe; native plant species; urban landscape; moss; seed mat

## 1. Introduction

Green roofs initially appeared in regions with temperate and cold climates, where they thrive without the need to irrigate [1]. However, for climates with hot and dry summers, as those of Mediterranean regions, the need to irrigate is unavoidable, as in these regions, plants on rooftops endure harsh conditions regarding temperature and insolation [2]. Therefore, green roof projects must include an irrigation system, increasing the implementation costs, as well as system management costs, namely additional water and energy consumption. One of the often referred benefits of green roofs is the ability to thermally insulate buildings [3], as this might present an interesting economic return. During summer, in regions with Mediterranean conditions, this may decrease costs with air conditioning, but if on the other hand, it is necessary to irrigate, the costs might outrun the benefits [4]. On a larger scale, this is also true in what concerns coping with the heat island effect in cities. Enlarging urban green roof areas can help mitigate the heat island effect [5–7], but if effective results are obtained only with large costly irrigation amounts, in economic terms, the results might again outrun the benefits. A different point of view is considering the mitigation of the heat island as an indispensable

ecosystem service, independently of the process cost in economic terms [8]. Either way, it is of major interest to find solutions that use the least possible irrigation amounts or even no irrigation.

During the occurrence of extreme drought events, priority uses may be determined and this often implies mandatory watering restrictions in landscape irrigation [9,10] privileging human, agriculture, and industry uses. The implementation of green roofs in areas prone to such events should prevent the situation, hence, low water demanding solutions should be adopted.

Limiting the availability of water to plants may impact plant development, growth and reproduction [11], and consequently, the aesthetic value of ornamental species. Green roof aesthetics are relevant for people's well-being [12], moreover if the visual and static interaction frontier is crossed and a deeper involvement with the ecology of the site is searched [13]. However, green roofs are also able to provide a list of ecosystem services (as recently reviewed by Reference [14]), not necessarily associated to an aesthetically pleasant environment. These services can be, for example, storm-water retention [14–16], increased urban biodiversity [17], noise reduction, air quality improvement, and temperature regulation of buildings or even, at a larger scale, cities [18]. Therefore, green roofs can be built as: i) aesthetically appealing environments; ii) ecosystem services providers; and iii) both, if environmental conditions allow to retain the aesthetic value. But aesthetics is a major driver of preference behaviour [19–21] and possibly only part of the end-users of green roofs in climates with hot and dry summers accept that sometimes there is a trade-off between aesthetics and ecosystem benefits, as less agreeable environments can provide relevant services.

A strategy to cope with water-limited environments might be to find nature-based solutions. One of the solutions often discussed is the use of native plant species, naturally adapted to drought conditions, and some studies have found adequate solutions balancing water consumption and aesthetics (e.g., [10,22–24]). Other authors [25] have found a strategy to cope with drought while using drought tolerant plants which are also high-water users, thus coping with rainfall water retention in green roofs. However, it has also been observed [26] that even plants chosen from dryland habitats may fail to survive in green roof conditions without irrigation, indicating that sometimes nature-based solutions cannot be transposed straightforwardly.

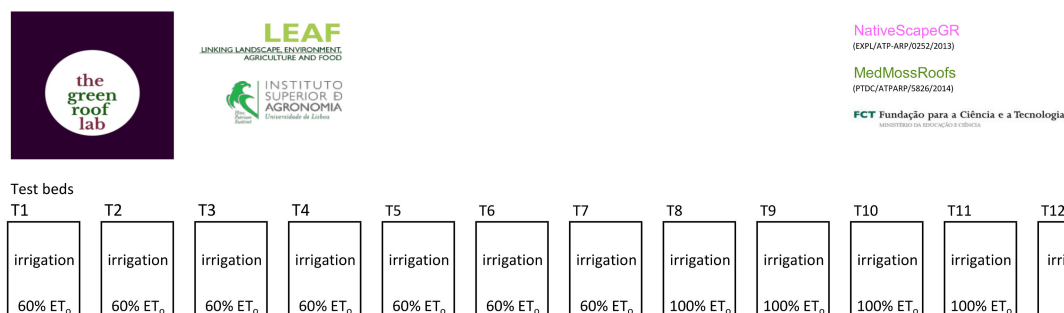
Regions with hot and dry summers might benefit from the use of green roofs concerning thermic control of buildings and cities [27], or other benefits, but a careful analysis of the costs is required, since the benefit implies using irrigation water. To help overcome this issue, innovative green roof design techniques coping with water limited environments can provide adequate sustainable solutions.

The objective of this study is to investigate solutions to minimize water use for the implementation of green roofs in climates with hot dry summers. Two case-studies were addressed, to test if: i) drought adapted native plant species are adequate to green roofs in central Portugal; ii) green roof construction materials with water retention capacity can help reduce irrigation amounts; iii) native species can sustain deficit irrigation while maintaining aesthetic value; iv) mixtures of vascular plants and mosses perform better than monospecific green roofs; v) moss-dominated biocrust roofs can survive without irrigation in the study conditions; vi) native species are able to thrive in pre-cultivated vegetation blankets for roofs; and vii) plants from walls and rocky environments of the region can endure roof conditions. All these possible solutions would allow reducing irrigation intensity or even avoiding the use of irrigation at all.

## 2. Materials and Methods

The work presented in this study has been developed in an experimental set installed at Instituto Superior de Agronomia (ISA, University of Lisbon, Portugal) on the rooftop of the Herbarium building (38°42'28.8"N, 9°11'0.43"W). The set was created in 2014, in the frame of the NativeScapeGR project (<http://www.isa.utl.pt/proj/NativeScapeGR/>) and consists of an array of metallic test beds (2.5 × 1 × 0.2 m<sup>3</sup>) that have been used to mimic different types of green roofs (Figures 1 and 2). The test beds are elevated 1 m above the roof surface and have a slope of 2.5%. They were constructed

as commercial green roofs, with a non-woven blanket in the bottom layer, above a drainage layer composed by polyethylene plates with cavities, a filter system (non-woven blanket), and a substrate.



**Figure 1.** Scheme of the experimental set with test beds at the rooftop of the Herbarium building at Instituto Superior de Agronomia, University of Lisbon (T1 to T12—test beds, ET<sub>0</sub>—reference evapotranspiration).

In a first phase (Phase 1), between 2014 and 2017, the test beds were planted with different arrangements of drought-adapted native plant species (Table 1) from central Portugal, namely vascular plants (*Lavandula luisieri* subsp. *luisieri* (L.), *Rosmarinus officinalis* L., *Brachypodium phoenicoides* (L.) Roem. & Schult.), and several species of mosses (mainly *Pleurochaete squarrosa* (Brid.) Lindb.) (Figure 3). Three different substrates were used: S1—a commercial substrate for intensive green roofs with 73% organic matter content, S2—a 2:1:1 blending of S1, sand, and clay soil, respectively, and S3—a commercial substrate for intensive green roofs with 20% organic matter content. Irrigation was provided in two different levels, 60 and 100% of reference evapotranspiration (ET<sub>0</sub>), being ET<sub>0</sub> defined as the evapotranspiration of a well-irrigated grass, with a defined height, albedo, and a fixed-surface resistance [28].

The MedMossRoofs project, initiated in 2016, is currently studying different desiccation tolerant bryophyte species (<http://medmossroofs.campus.ciencias.ulisboa.pt/>), including *Didymodon* sp., *Tortella nitida* (Lindb.) Broth., and *Pleurochaete squarrosa* (Lindb.) Broth., native to the Mediterranean and completely adapted to its dry hot climate, with the objective of increasing their growth rate in controlled chambers and transplant them to the test beds.

In the end of 2017, Phase 1 experiments were partially discontinued in order to study new vascular native plants in green roof conditions, while maintaining mosses, as these were a promising innovative solution.



**Figure 2.** General view of the test beds at the rooftop of the Herbarium building at Instituto Superior de Agronomia, University of Lisbon, Portugal.

In a second phase (Phase 2), from the beginning of 2018, all the test beds were refilled with the same substrate (S4, a commercial substrate for extensive green roofs, similar to S1) presenting 71% organic matter content, to facilitate treatment comparisons (Table 2). Test beds 1–5 and 8–10 were planted with species that thrive in walls and roofs of old buildings in the region, while maintaining the bryophyte species *Pleurochaete squarrosa* (Brid.) Lindb. (apiWall—Another plant in the wall, [http://www.facebook.com/pg/thegreenrooflab/photos/?tab=album&album\\_id=952890424869636](http://www.facebook.com/pg/thegreenrooflab/photos/?tab=album&album_id=952890424869636)) in test beds 11 and 12. Test beds 6 and 7 were left without plants.

A first adaptation test was performed with native plants (*Centranthus ruber* (L.) DC., *Asphodelus fistulosus* L., *Antirrhinum linkianum* Boiss. & Reut, *Sedum* spp., *Phagnalon saxatile* (L.) Cass., *Reichardia picroides* (L.) Roth, *Medicago orbicularis* (L.) Bartal., *Andryala integrifolia* L., *Senecio vulgaris* L.) collected on March 2017 in old walls of an unfinished part of the National Palace of Ajuda (Lisbon), before the beginning of recent renovation works. The collected plants were transplanted into a nursery and kept there for 5 months, to evaluate survival. Plants of some of the mentioned species were later planted in the test beds (*Asphodelus fistulosus*, *Centranthus ruber*, *Antirrhinum linkianum*, *Sedum sediforme*), either coming from a nursery (Sigmetum—<http://sigmetum.blogspot.com/>) or transplanted from walls in the neighbourhood. The number of flowers and vegetative development (ground cover) were evaluated by visual and photographic techniques between February and September 2018. Data concerning the number of flowers were analysed with two-way ANOVA.

Pre-cultivated vegetation blankets (1 × 2.5 m) for later use in the test beds were prepared with plants well adapted to growth in walls and rocky environment, as well as other plant species, using an organic geotextile blanket, made with a coconut fibre matrix, reinforced with a fine photodegradable net for material strength improvement (Ecosalix®, EROMAT 6s). A small test was performed to experiment the seeds adhesion to geotextile without compromising seeds germination rates. Seven experiments took place, six with different concentrations of mixture and one control test. Small portions of the organic mat were placed in containers, to function as a physical barrier, to the water and roots in the lower level. Several mixtures were then prepared to test the adhesion of the seeds to the organic blanket. Mixture concentrations made were 2:1 mixture of water and flour, 4:1 mixture of water and flour, 60 ml with half a sheet of gelatine, 60 ml for one sheet of gelatine, 2:1 concentration of



water and flour with one gelatine sheet, and 4:1 mixture of water and flour with half a sheet gelatine, and control with just water.

So far, research on pre-cultivated vegetation blankets for green roofs mostly addresses plants of the genus *Sedum* (e.g., [29,30]). *Sedum* plants cumulate water in leaves as a drought adaptation mechanism, and thus have features for green roofs in hot, dry environments. However, by cumulating water, since water has a high heat capacity, they also contribute to conserve heat in the roof, by comparison to other plants that present lower leaf hydration, being a less interesting solution in the context of thermal insulation of buildings or heat island control in cities. Thus, seed blankets were prepared using two seed mixtures of plants disregarding the genus *Sedum*. First mixture of seed consisted of *Centrathus ruber* (10%), *Asphodelus fistulosus* (30%), *Sanguisorba verrucosa* (30%), *Papaver rhoeas* (20%), and *Capsela bursa-pastoris* (10%); the second seed mixture consisted of *Trifolium angustifolium* (30%), *Brisa maxima* (30%), *Silene scabriflora* (10%), *Stachys germanica* (10%), *Teucrium scorodonia* (20%). A thin layer of substrate (S4) was used over the geotextile to receive the seeds. The adhesion mixtures were not used as they didn't prove to be effective enough, as further explained. A sprinkler irrigation system was installed (Rainbird 10 cm, ref 11744733, regulated to 0.15 m<sup>3</sup>/h). Four irrigation events per day were programmed (every 6 hours), with the duration of 3 minutes each.

**Table 1.** Description of test beds: species, irrigation (% of reference evapotranspiration) and substrates—NativeScapeGR and MedMossRoofs projects, (T1 to T12—test beds, I—irrigation, ET<sub>o</sub>—reference evapotranspiration, S —substrates [see text for composition]).

Test Beds	Vegetation				I	S
	<i>L. luisieri</i>	<i>R. officinalis</i>	<i>B. phoenicoides</i>	Mosses		
T1	✓	✓	✓	✓		S2
T2				✓		S3
T3			✓			S2
T4	✓				60% ET <sub>o</sub>	S1 + S3
T5	✓	✓	✓	✓		S1
T6		✓				S1
T7			✓			S1
T8		✓				S1
T9			✓			S1
T10	✓				100% ET <sub>o</sub>	S3
T11						S3
T12				✓	No I	S3



**Figure 3.** Test bed with vascular plants and mosses at the rooftop of the Herbarium building at Instituto Superior de Agronomia, University of Lisbon, Portugal.

**Table 2.** Description of test beds: species, irrigation (% of reference evapotranspiration), and substrates—apiWall and MedMossRoofs projects, (T1 to T12—test beds, I—irrigation, ET<sub>o</sub>—reference evapotranspiration, S4—substrate).

Test Beds	Vegetation					I	S
	<i>A. fistulosus</i>	<i>C. ruber</i>	<i>A. linkianum</i>	<i>S. sedifforme</i>	Mosses		
T1	1	2	4	3	✓		S4
T2	1	2	2	2			S4
T3	1	2	2	2			S4
T4	1	2	2	2		60% ET <sub>o</sub>	S4
T5		1	5	3	✓		S4
T6							S4
T7							S4
T8	1	2	2	2			S4
T9	1	2	2	2		100% ET <sub>o</sub>	S4
T10	1	2	2	2			S4
T11					✓		S4
T12					✓	No I	S4

S4—Commercial green roof substrate, texture not classified due to high organic matter content.

### 3. Results and Discussion

#### 3.1. Use of Drought-Adapted Native Species

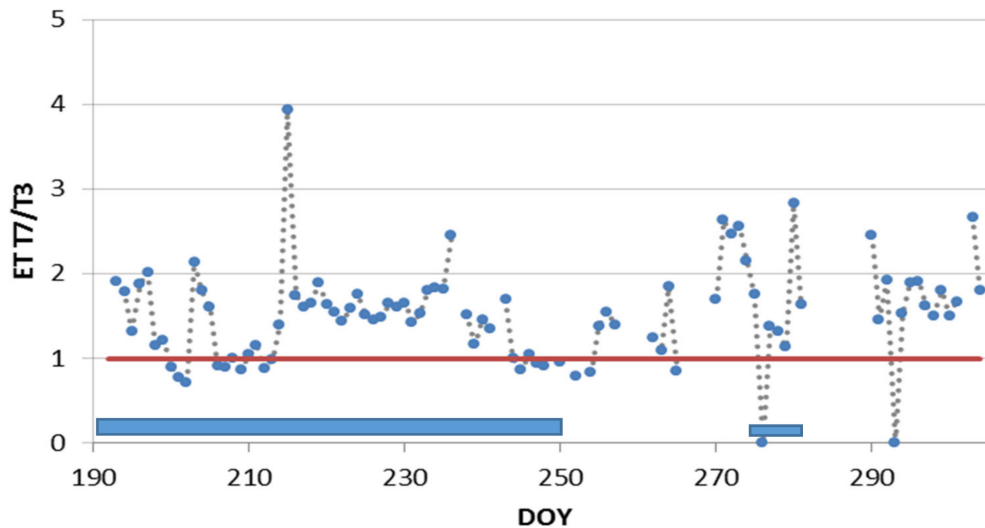
In regions with Mediterranean conditions, green roof plants must endure difficult environmental conditions to survive, therefore tolerance to drought can be considered one of the essential selection traits [11,31]. Thus, the type of plants chosen is quite determinant of the success of the green roof. A logic approach is to use plants that are adapted to local natural conditions, especially native plants, plants that are indigenous to a certain area in geologic time. Plants studied during the Phase 1 of the study (NativeScapeGR project) were all native plants and proved to be suitable to green roofs, evidencing adequate development and growth during the experiments. Moreover, in a global approach, the use of two different irrigation levels (100% ET<sub>o</sub> and 60% ET<sub>o</sub>) did not induce noticeable differences in the aesthetic value of test beds with different combinations of vascular plants and mosses [23]. Other authors have also obtained good results with native plants in green roofs, either species that require very low irrigation amounts [32] or species ecologically adapted to shallow substrates [24].

When all the species were combined in the same test bed, some plant features of these native species showed to be potentially useful for the use in green roofs. For example, *Brachypodium phoenicoides* is an herbaceous hemicryptophyte perennial, therefore its aerial part might dry totally or partially during summer, as also observed by Reference [10], and, although decreasing its aesthetic interest during this season, this mechanism allows the plant to survive during summer with very low water requirements. While combined with other perennials that do not present such behaviour, maintaining their aerial part during the whole cycle, its aesthetic impact is not relevant, while contributing to the sustainability of the structure. Additionally, from the three vascular species selected in the study, *B. phoenicoides* presented the best behaviour concerning the potential thermal insulation capacity [33], which is probably related with a larger ground cover and biomass production, when compared to *L. luisieri* and *R. officinalis*. This high ability to cover the substrate was also observed for *B. phoenicoides* in another study in green roofs [10].

#### 3.2. Use of Structural Materials with Water Retention Capacity

At the rooftop of a building, plants are exposed to harsh conditions of temperature, radiation, and wind, while thriving in shallow substrates, with limited capacity to hold water. Therefore, in dry hot climates, structural components of the green roof that can help to retain water can play an important role. Commonly, green roof systems include the following layers from top to bottom: vegetation, lightweight substrate, filter, drainage layer, moisture retention layer, and root-resistant

waterproofing barrier. Water is mostly retained in the substrate, the drainage layer and the moisture retention layer. An example of the substrate effect on water retention at our experimental set, during Phase 1, is presented in Figure 4. Test bed 7 had a commercial substrate for green roofs (S1), with high organic matter content and test bed 3 had a mixture (S2) of the same substrate (50%) with sand (25%) and clay soil (25%). In T7 evapotranspiration was consistently higher, evidencing a larger quantity of water available for plants, since all the other factors (vegetation and irrigation level) were equal.

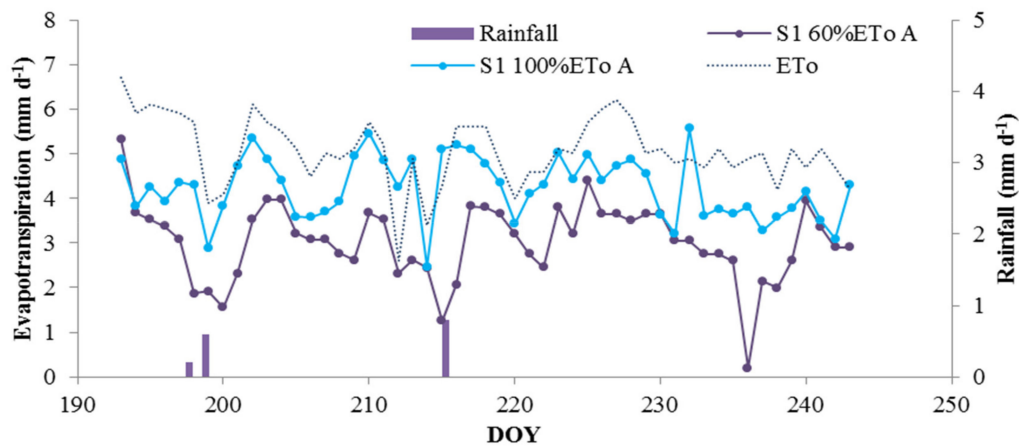


**Figure 4.** Relative evapotranspiration (ET) in test beds with *Brachypodium phoenicoides* submitted to the same irrigation level (60% of reference evapotranspiration,  $ET_0$ ) and different substrates; blue rectangles represent irrigation periods.

Two of the construction elements, the drainage and the water retention layers, can act as interesting reservoirs for water. In our experimental set, either for Phase 1 or 2 of the study, since the structure was not changed, both elements could retain up to 8 mm of water, which is approximately double the water evapotranspired in a typical summer day for deficit irrigation conditions, for example in a *Rosmarinus officinalis* test bed (Figure 5). This means that this stored water could supply a green roof with *Rosmarinus officinalis* for two summer days, instead of being drained to the sewage system. The ability of construction elements to store water has also been addressed for green roofs with a shallow substrate (40 mm) which could still maintain high water retention due to drainage and other elements in the structure [34].

### 3.3. Deficit Irrigation vs. Aesthetic Value

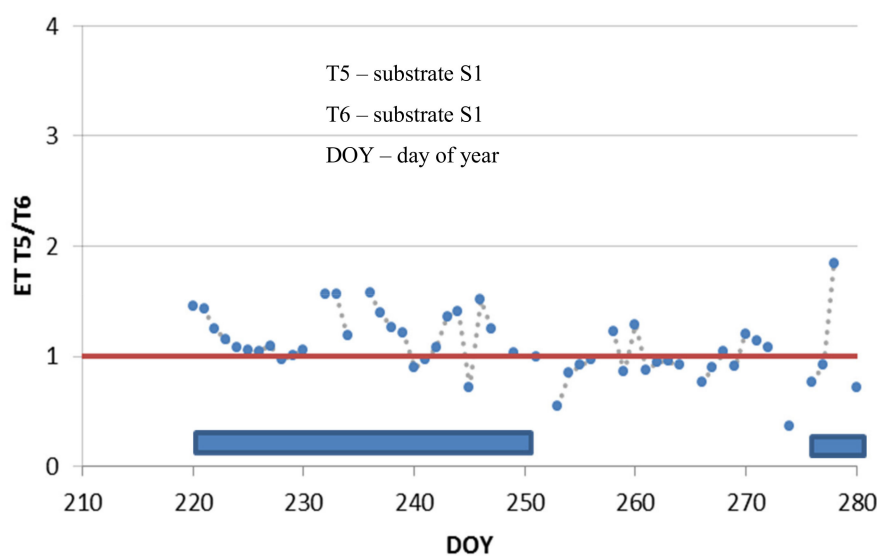
Figure 5 presents the evapotranspiration of *Rosmarinus officinalis* under two different irrigation levels (Phase 1 of the study), showing that the lower level, corresponding to deficit irrigation, produced, as expected, lower evapotranspiration rates. However, these differences were not significantly reflected in the aesthetic value that was in general maintained for the other plant species studied in Phase 1 of the experiments (further detailed in [23]). This result indicates that it is possible to use those native species under deficit irrigation without losing the expected aesthetic value, which is an interesting plant feature considering that the end-users' preferences more frequently privilege aesthetics, regarding other aspects (e.g., environmental concerns) [19–21].



**Figure 5.** Actual evapotranspiration in test beds with *Rosmarinus officinalis* submitted to two irrigation levels (60% and 100% of reference evapotranspiration,  $ET_0$ ) and rainfall events (DOY—day of year).

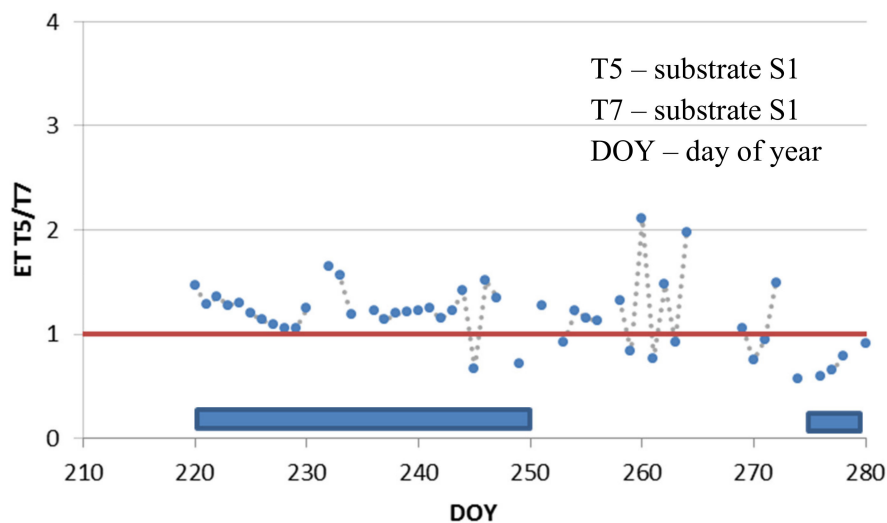
### 3.4. Mixtures of Vascular Plants and Mosses

For test beds with mixtures of *Lavandula luisieri*, *Rosmarinus officinalis*, *Brachypodium phoenicoides*, and *Pleurochaete squarrosa* (Phase 1), evapotranspiration was larger in comparison with test beds with only one species. Figure 6 shows the evapotranspiration of test bed 5 (T5, with a mixture of vascular plants and mosses) in relation to T6 (with *Rosmarinus officinalis* only). This relative evapotranspiration was higher than 1 most of the time (1.2 in average), during irrigation periods, indicating a higher water retention in T5, probably due to the presence of mosses, since irrigation levels and substrates were the same. This fact results from the high-water retention of the mosses [35] that can benefit the soil moisture content around the vascular plants, increasing their water use efficiency. The same effect can be observed for *Brachypodium phoenicoides* (T7), even though not so pronounced (Figure 7). The presence of taller vascular plants also provides a shelter for the mosses against solar radiation and wind during summer and helps conserve moisture, as observed by other authors [36]. This mixed composition of species with complementary features constitutes a nature-based solution, replicating what is commonly observed in natural conditions, where biodiversity can act as a driver of ecosystem functioning [37,38].



**Figure 6.** Relative evapotranspiration of a test bed with all the vascular plants mixed with mosses (T5) and T6 (*Rosmarinus officinalis*) submitted to an irrigation level of 60% of reference evapotranspiration ( $ET_0$ ) (bars represent irrigation periods).





**Figure 7.** Relative evapotranspiration of a test bed with all the vascular plants mixed with mosses (T5) and T7 (*Brachypodium phoenicoides*) submitted to an irrigation level of 60% of reference evapotranspiration ( $ET_0$ ) (bars represent irrigation periods).

### 3.5. Use of Moss-Dominated Biocrust Roofs

For the non-irrigated (rainfed conditions) test bed, the mosses acquired a dry and brown aspect during summer and after the first rains in September they restarted activity, showing it was possible to maintain the selected species without irrigation in such conditions. These moss-dominated biological soil crusts (biocrusts) are poikilohydric with desiccation tolerance, i.e., they present the ability to lose almost all water from inside the cells and upon rehydration regain normal function [39–42] and can be grown in two months under controlled climatic conditions [43,44].

A biocrust roof of this type could be an interesting solution for low-cost green roofs in urban areas with dry and hot summers, since no irrigation is required and can increase water use efficiency of other vascular plants if irrigation is required. Furthermore, floods in urban areas resulting from the increase of flash rain events (high water content in a small period) due to climate change can be attenuated by the ability of some mosses to retain water up to eight times their dry weight [35].

### 3.6. Precultivated Vegetation Blankets for Roofs

The tests for seed adhesion to the geotextile blanket with the different combinations of water, flour and gelatine (Phase 2 of the study), showed that the only suitable combinations were the mixture 4:1 of water and flour or just plain water, being this last the solution the one providing the higher germination rate. Therefore, no clear advantage arose from the use of agglutinants. Moreover, it was observed that the roots quickly developed, and in the absence of substrate, could not sustain the development of the aerial part of the plant until an acceptable coverage of the blanket because the medium did not have the capacity to retain an adequate volume of water. Thus, the definite blankets were prepared just with a thin layer of substrate to overcome these difficulties. Consequently, the blankets were seeded as described in Section 2. Results showed that both seed mixtures were able to germinate and that the seedlings fixed well to the blanket, although the coverage for mixture 1 was higher (around 40% of the surface, eight weeks after seeding). It was also possible to observe that the roots of the seedlings crossed the geotextile layer, reaching the exterior in both cases. Apart from the ordinary benefits of pre-cultivation (increased plant survival, uniformity, readiness, etc.), the ability of blankets to act as mulches makes them interesting for green roofs in what concerns water conservation. Further experimentation for this topic is needed but mixture 1—*Centrathus ruber*, *Asphodelus fistulosus*, *Sanguisorba verrucosa*, *Papaver rhoeas* and *Capsela bursa-pastoris*—seems a more promising solution, for our conditions, considering its initial development.

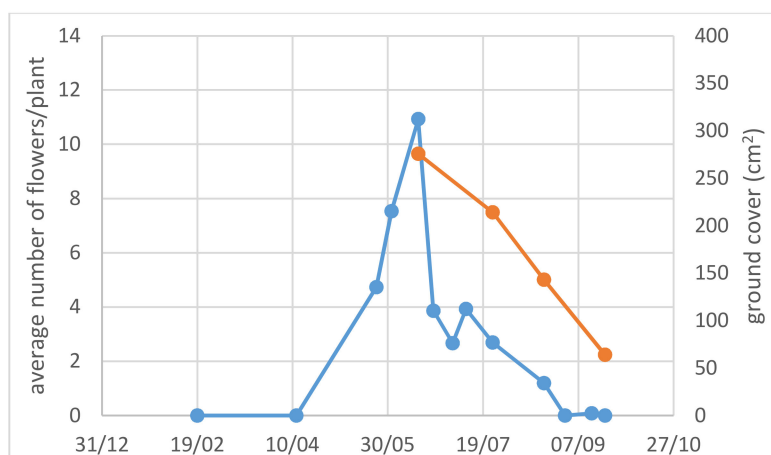
### 3.7. Wall Plants Transplanted to Roofs

All the plants transplanted from walls to the nursery survived, evidencing also an appreciable growth (Phase 2, Figure 8). This indicates that transplantation from the wall medium to a common commercial substrate is viable, although in a less demanding environment (the nursery) than a roof, considering temperature, radiation, and wind conditions. Also, wall species planted in the test beds, as a direct transplantation from roofs and walls, were well adapted and with a normal development.

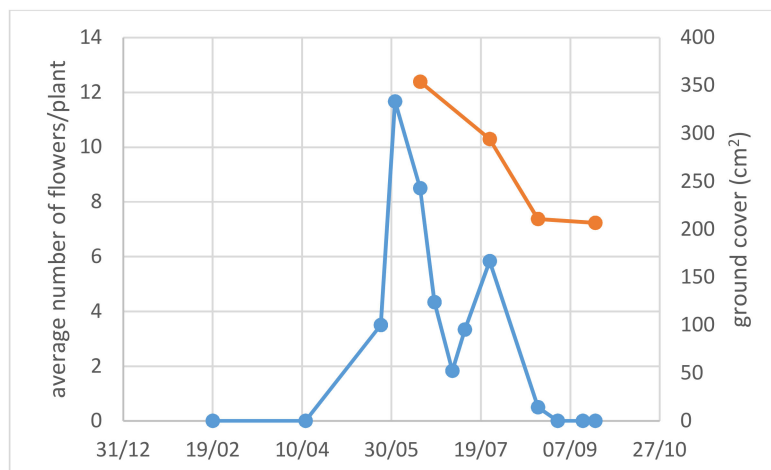


**Figure 8.** Test bed with *Antirrhinum linkianum*, a common plant in roofs and walls of old buildings, at the rooftop of Instituto Superior de Agronomia, University of Lisbon.

Figures 9 and 10 present an example for the analysis between February and September of the average number of flowers per plant and ground cover for *Antirrhinum linkianum*. The number of flowers per plant was similar for both levels of irrigation, along the studied period, and the statistic test performed showed that there were no significant differences between treatments. This implies that when irrigation was scheduled to provide only 60% of  $ET_0$ , plants were able to blossom similarly to those that were submitted to a higher level of irrigation. Ground cover was similar for both irrigation regimes until the end of summer. However, after this date, ground cover values decreased more sharply for the lower irrigation conditions, suggesting a drought effect on the plants.



**Figure 9.** Average number of flowers per plant (blue) and ground cover (orange) of *Antirrhinum linkianum*, with irrigation at the 60%  $ET_0$  level (test beds 1 to 5).



**Figure 10.** Average number of flowers per plant (blue) and ground cover (orange) of *Antirrhinum linkianum*, with irrigation at the 100%  $ET_0$  level (test beds 8 to 10).

#### 4. Conclusions

Several techniques for the design of green roofs in regions with Mediterranean conditions are described and analysed, as a result from the practices developed in the frame of three research projects of the University of Lisbon, aiming to optimize water use in such structures. The techniques studied were: i) use of (native) drought-adapted species; ii) use of construction materials with water retention capacity; iii) deficit irrigation maintaining aesthetic value; iv) mixtures of vascular plants and mosses; v) biocrust roofs; vi) pre-cultivated vegetation blankets for roofs; and vii) wall plants transplanted to roofs.

The main conclusions indicate that: the native plants so far studied were adequate to sustain deficit irrigation without significant loss of aesthetic value. Although aesthetics are important, other services provided by green roofs, such as particle retention, water retention against flash rain events, and carbon sequestration must be considered, possibly assuming a more important role in the urban environment; by making a compromise between the two approaches, a reasonable solution consists of moss (biocrust) roofs that can still be aesthetically pleasant and perform more as a functional living roof. Water retaining materials and substrates can have an important role in such conditions; the most interesting solution for plant selection was the mixture of vascular plants and mosses, which is a nature-based solution, since it is a replication of what is observed in the natural environment. A relationship was established between mosses, which present a larger water retention capacity, and the vascular plants, which can use the retained water. Also, although mosses are drought-tolerant, being close to vascular plants allows them to maintain hydrated conditions during longer periods, and therefore present a better performance, providing their services during an enlarged time frame. This new type of green roof can help adaptation to the effects of climate change, like increased temperature and light exposure as well as decreased precipitation.

Pre-cultivated blankets showed to be a promising solution to help conserving water in green roofs and preliminary experiences with local plants from walls and rocky environments indicate they can survive and develop in green roofs.

**Author Contributions:** T.A.P. conceived and designed the experiments; collected and analysed data; wrote the paper; R.C.d.C. participated in the conception and analysis of data of NativeScapeGR and MedMossRoofs and in the writing of paper; P.A. participated in the conception of apiWall and in the writing of the paper; D.M. performed the experiments of apiWall and analysed the data.

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