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Research Article

Adaptation of *Salvia fruticosa*, *S. officinalis*, *S. ringens* and interspecific hybrids in an extensive green roof under two irrigation frequencies

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Abstract

With the ultimate goal of introducing new species of sage to the green roof industry, the adaptation of the Mediterranean sage species *Salvia fruticosa, S. officinalis*, *S. ringens* and the interspecific hybrids *S. fruticosa* × *S. ringens* and *S. officinalis* × *S. ringens* was investigated, under normal and sparse irrigation in an extensive green roof in Athens, Greece. Rooted cuttings were planted (April 2021) on shallow (10 cm) substrate (grape-marc compost: perlite: pumice, 3:3:4, v/v) and irrigated when substrate moisture was 16-22% (normal irrigation) or 7-11% (sparse irrigation). All sage types established satisfactorily on the green roof, even under sparse irrigation, except *S. fruticosa,* which had the highest vegetative growth and at the end of the experiment (September 2021) showed the highest mortality rate regardless of irrigation frequency. Similar to the *S. fruticosa* response showed the *S. fruticosa* × *S. ringens* hybrid under normal irrigation. Both hybrids, *S. fruticosa* × *S. ringens* and *S. officinalis* × *S. ringens* had a lower mortality rate under sparse irrigation compared to the parental species. *S. officinalis* × *S. ringens* formed more lateral shoots than its parental species and had an almost spherical compact canopy, which is a nice feature for an ornamental plant. *S. officinalis* and *S. ringens* developed bigger horizontal diameter, which is valued for rapid substrate coverage in a green roof installation. All sage types flowered except *S. fruticosa.* All sage types showed higher values of stomatal resistance under sparse irrigation, while ΦPSIIo values under both irrigation frequencies indicated normal operation of the photosynthetic apparatus. *S. officinalis*, *S. ringens* and *S. officinalis* × *S. ringens* hybrid are highly recommended for sustainable extensive green roofs in arid/semi-arid regions.

Keywords: drought resistance; limited irrigation; Mediterranean native plants; Mediterranean sage species; urban horticulture; xeriscaping

Introduction

Green roofs of various types are nature-based solutions for innovative green strategy plans for urban areas. They provide multiple direct and indirect environmental, ecological, social, and economic benefits presented extensively in a number of review papers (Cook and Larsen, 2021; Joshi and Teller, 2021; Calheiros *et al.*, 2022; Nguyen *et al.*, 2022). Contribution to carbon sequestration, improvement of air quality and

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reduction of the urban heat island effect (Berardi *et al.*, 2014; Whittinghill *et al.*, 2014; Shafique *et al.*, 2020; Seyedabadi *et al.*, 2021; Rafael *et al.*, 2021; Fleck *et al.*, 2022) are of the most important green roof benefits opposing the climate crisis. Further, green roofs, absorbing rainwater by the substrate and plants, have the ability to slow and reduce storm water runoff (Carbone *et al.*, 2015; Raimondi and Becciu, 2021), while they promote urban biodiversity (Maclvor and Lundholm, 2011). The effectiveness of green roofs, which depends on parameters such as weather, construction, materials and design, should lead to their promised benefits, although they are not always easily measurable (Joshi and Teller, 2021; Liu *et al.*, 2021).

The Mediterranean basin because of its geophysical peculiarities is considered a "hot spot" of global climate crisis (Lionello and Scarascia, 2018; Tuel and Eltahir, 2020), which has caused problems in water management of crops. Most Mediterranean cities have a long history and thus a significant part of them consists of old buildings. Old Mediterranean buildings that were evaluated during the summer were found to be more polluting than newer buildings and in fact do not have thermal comfort resulting in consuming excessive energy (Caro and Sendra, 2020). The installation of green roofs on such buildings is a promising solution to improve the urban environment. However, the weight of the construction when installing green roofs on aged buildings that are unlike to support a heavy green roof and the water availability are fundamental issues that need to be addressed first. At the same time, biodiversity and preservation of the local vegetation character should also be taken into account.

Experiments that are conducted diligently aim at identifying drought-resistant plants that have a satisfactory appearance in addition to their ecological benefits (Du *et al.*, 2019; Yee *et al.*, 2022). Evaluation of native species under diverse growth conditions is considered a crucial stage in developing suitable green roof plants (Cáceres *et al.*, 2018). In addition, they are more attractive to pollinators than non-native plants (Rahimi *et al.*, 2022) and can play a prominent role in insects' survival as there has been a decline in their populations and diversity (Foley *et al.*, 2005). A large percentage of the Mediterranean flora is in danger of extinction (Orsenigo *et al.*, 2018; Kougioumoutzis *et al.*, 2021) and there are various scenarios for plant species and their survival, including those used in green roofs (Vanuytrecht *et al.*, 2014).

Native plants although they are expected to adapt well in a specific local area at ground level, are not certain to do the same on a green roof in the same area (Butler *et al.*, 2012). Plants on a green roof will endure additional abiotic stress due to higher exposure to radiation and wind in a shallow substrate. Thus, the aesthetic value of plants and the benefits of green roof for the ecosystem could be threatened.

Mediterranean native species with minimal water requirements have been shown to adapt to extensive green roofs with very shallow light-weight substrate (Nektarios *et al.*, 2011; Papafotiou *et al.*, 2013; Azeñas *et al.*, 2018; Papafotiou *et al.*, 2018; Zanin and Bortolini, 2020; Tassoula *et al.*, 2021; Esfahani *et al.*, 2022). However, the value of many aromatic native plants as green roof plants has not been adequately investigated.

The genus *Salvia*, member of the mint family (Lamiaceae), is one of the largest and has many species used as medicinal, culinary or ornamental plants worldwide. Mediterranean *Salvia* spp. however have not been widely explored for use as ornamental plants, apart from *S. officinalis* that is found in many varieties as landscape plant and much less *S. fruticosa* (Raimondo et *al.*, 2015; Schmiderer and Novak, 2020).

S. fruticosa Mill. (*S. triloba* L., Greek sage), *S. officinalis* L. (Dalmatian sage, or common sage or sage) and *S. ringens* Sibth. & Sm. are perennial evergreen subshrubs native in the Eastern Mediterranean region including Greece, being part of the macchia vegetation. *S. fruticosa* and *S. officinalis* have a long tradition of use, since the antiquity, as medicinal and culinary plants. They both are strongly aromatic plants with a high content of essential oils in their leaves.

S. fruticosa is endemic to the eastern Mediterranean at altitudes 1-700 m (Thanos and Doussi, 1995) and is widely used for the preparation of an herbal tea ('faskomilo'). It is a rather tall woody herb, up to 120 cm tall and wide, with flower stalks rising 30 cm above the foliage, which is, covered with hairs that give a silvery appearance (Figure 1A). It is characterized by wide variation in leaf shape depending on geographical area; often the leaves have 1-2 pairs of small lobes below the main one. It flowers from early spring to beginning of summer and the flowers growing in whorls along the inflorescence (Figure 1A) are lilac, pink or sometimes white (1.6-2.5 cm long) (Blamey and Grey-Wilson, 1993). It is hardy to -6 °C and very drought resistant (Clebsch and Barner, 2003).

S. officinalis is one of the most important species of the genus *Salvia* worldwide naturalized in many parts of the world and cultivated in many varieties as medicinal and ornamental plant. It is a medium size woody herd, up to 60 cm tall and wide, at a medium rate, with branches spreading to erect and leaves oblong to elliptical, rugose gray-green above but white felted beneath and margin finely toothed (Figure 1B). It flowers in May – July with mainly lavender flowers (Figure 1B), but also pink or white (2.0-3.5 cm long) (Tutin *et al.* 1972; Blamey and Grey-Wilson, 1993). In Greece, it is found northwest at altitudes between 600 and 950 m (Kintzios, 2000).

S. ringens, unlike the other two species, is a small herbaceous plant, up to 30 cm tall and wide, with a slightly woody base, which forms a basal clump of dark green appressed-hairy pinnately divided leaves (Figure 1C). In late spring and through summer it develops tall (60 cm), branched flowering stems with 2-4 large (about 3.8 cm long) violet-blue or blue flowers (Figure 1C). It is found at altitudes from 490 up to 1,900 m and it is resistant to low temperatures (Tutin et *al*., 1972).

The horticulture industry is constantly looking for new plant species and varieties to introduce to market. Therefore, successful crosses were made between *S. fruticosa* or *S. officinalis* with *S. ringens* that incorporated interesting characteristics of each species to the produced hybrids (Papafotiou *et al*., 2021). The *S. fruticosa* × *S. ringens* hybrid (Figure 1D) has the height, the erect shoots and the intensely hairy leaves of *S. fruticosa,* but the leaves are slightly fragrant pinnately divided like that of *S. ringens*. Its flowering stems are longer (about 80 cm) and flowers are more sparsely arranged than those of *S. fruticosa* and the flower color is light purple. The *S. officinalis* × *S. ringens* hybrid (Figure 1E) has inherited from *S. ringens* the very slightly fragrant pinnately divided leaves, the long flowering stems, which however bear more flowers than *S. ringens* influenced by *S. officinals,* of light violet-blue colour, while it has the height of *S. officinalis*. Both *S. fruticosa* × *S. ringens* and *S. officinalis* × *S. ringens* hybrids have been shown to respond better to water stress in greenhouse conditions compared to *S. fruticosa* (Papafotiou *et al*., 2021).

S. fruticosa and *S. officinalis* as members of the macchia vegetation are drought resistant plants. However, *S. fruticosa*, although native to southern warmer regions compared to *S. officinalis*, often has survival problems in gardening attributed to limited water supply, especially in extensive green roofs, in contrast to *S. officinalis* that shows a higher drought resistance (Kokkinou *et al*., 2016). The latter is considered suitable for use in extensive green roofs (Savi *et al*., 2013; Raimondo *et al*., 2015).

The aim of the present work was to study comparatively the adaptation of *S. fruticosa, S. officinalis, S. ringens* and their hybrids *S. fruticosa* × *S. ringens* and *S. officinalis* × *S. ringens*, in an extensive green roof in Athens, Greece, under two irrigation frequencies, one normal and one sparse. Plant growth along with physiological parameters were recorded and evaluated during a five-month period including summer.

Figure 1. Inflorescence and plant canopy of *Salvia fruticosa* (A), *S. officinalis* (B), *S. ringens* (C), *S. fruticosa* × *S. ringens* (D) and *S. officinalis* × *S. ringens* (E) in the green roof.

Materials and Methods

Experimental setup

The experiment took place on a second-floor flat roof (12 m approximate height) at Agricultural University of Athens (37° 59′ N, 23° 42′ E) from early April 2021 to mid-September 2021. Rooted stem tip cuttings of *Salvia fruticosa*, *S. officinalis*, *S. ringens* and of their hybrids *S. fruticosa* × *S. ringens* and *S. officinalis* × *S. ringens* (developed in the research project SALVIA-BREED-GR, project code: T1EDK-04923) were planted in experimental modules, 60 cm long, 40 cm wide and 15 cm deep. The cuttings were excised in January-February 2020 from mature mother plants grown in a greenhouse, which were routinely used as cutting source, rooted on peat-perlite (1:1 v/v) and kept in the greenhouse without any fertilization until their transplanting in the experimental modules. The modules included the green roof infrastructure: substrate moisture retention and protection of the insulation mat FLW-500, drainage element Diadrain-25H and filter sheet VLF-150 (Landco Ltd, Diadem Green Roof Systems, Athens, Greece). The substrate was 10 cm deep and was a mix of grape-marc compost: perlite: pumice (3:3:4, v/v, respectively).

The characteristics of the grape-marc compost (Anagnostou- Soils, Compost & Substrates, Athens, Greece) were the following: pH in extract (1:5) 8.8, ash (550 °C) g/100 g 45.5, EC 3050 μS/cm, total nitrogen (N) g/100 g 2.6, ammoniacal nitrogen mg/Kg 1451, C/N ratio 10.5, P_2O_5 soluble in inorganic acids (total) g/100g 0.9, K (total potassium) g/100g 2.1, Na (total sodium) g/100 g 0.2, Ca (total calcium) g/100 g 10.9, Mg (total magnesium) g/100 g 1.1, Fe (DTPA extractable) mg/Kg 77, Mn (DTPA extractable) mg/Kg 89, Zn (DTPA extractable) mg/kg 37, Cu (DTPA extractable) mg/Kg 2.6, B (DTPA extractable) mg/Kg 24. The chemical properties of the pumice (dimensions 0-3 mm, Anagnostou- Soils, Compost & Substrates, Athens, Greece) were: SiO_2 71.91%, Al_2O_3 12.66%, Fe_2O_3 1.13%, CaO 1.46%, MgO 0.32%, SO_3 0.03%, K_2O 4.30%, NaO 3.45%, others 0.21%. Perlite (particles diameter 1-5 mm, Perterra, NORDIA S.A., Athens, Greece) had bulk density 80 K/m^3+15%, soluble Cl-<0.01%, sulfates soluble in acids SO_3<0.01%, total S <0.01% and heavy metals below the limits permitted by law.

An experiment with two factors was conducted. The two factors were: plant type (*S. fruticosa*, *S. officinalis, S. ringens*, *S. fruticosa* × *S. ringens* and *S. officinalis* × *S. ringens*) and irrigation frequency (normal and sparse). Therefore, ten treatments were applied (5 plant types × 2 irrigation frequencies). Six containers per treatment were used with two plants of the same type in each container, i.e., 12 plants per treatment. The containers were arranged following the completely randomized design.

Irrigation

Throughout the dry season irrigation schedule was applied by automatic drip irrigation on the surface of the growth substrate, by two drippers placed at equal distances from the center of the container and the two plants (dripper supply 4 L h^{-1}). Each irrigation event was applied before sunrise and lasted for an hour to succeed full run off. The first week after planting, irrigation was applied every 2 days in order for the plants to overcome the transplant stress. Then all the plants were exposed to a preliminary drought experiment for determining the number of days that the plants could withstand between two irrigation events. The daily measurements of the substrate water content (% v/v) were recorded (moisture meter HH2, with a soil moisture dielectric sensor WET-2, Delta-T devices, Cambridge, U.K.) as described by Tassoula *et al.* (2015) and the wilting symptoms of each species determined the sparse irrigation frequency. Two irrigation frequencies were applied, normal and sparse, when substrate moisture was 16-22% and 7-11%, respectively. Substrate water content tests were carried out regularly until the end of the experiment. Based on the above, irrigation was applied every 3 days (normal) and 5 days (sparse) in April and May and during the rest of the experimental period every 2 and 4 days, respectively.

Meteorological data

Meteorological data concerning average, minimum and maximum weekly air temperature, total weekly rainfall, average weekly wind speed, relative humidity and total radiation during the experimental period are presented in Figure 2. Air temperature, rainfall and wind speed data were collected from a meteorological cage (ELEV: 60 m LAT: 37° 58' 42" N LONG: 23° 42' 56" E), which was very close to the place where the experiment was conducted (http://meteosearch.meteo.gr/data/athens/2021-08.txt), while relative humidity and radiation data are from the meteorological cage of the Laboratory of General and Agricultural Meteorology of the Agricultural University of Athens, which is adjacent to the experimental space.

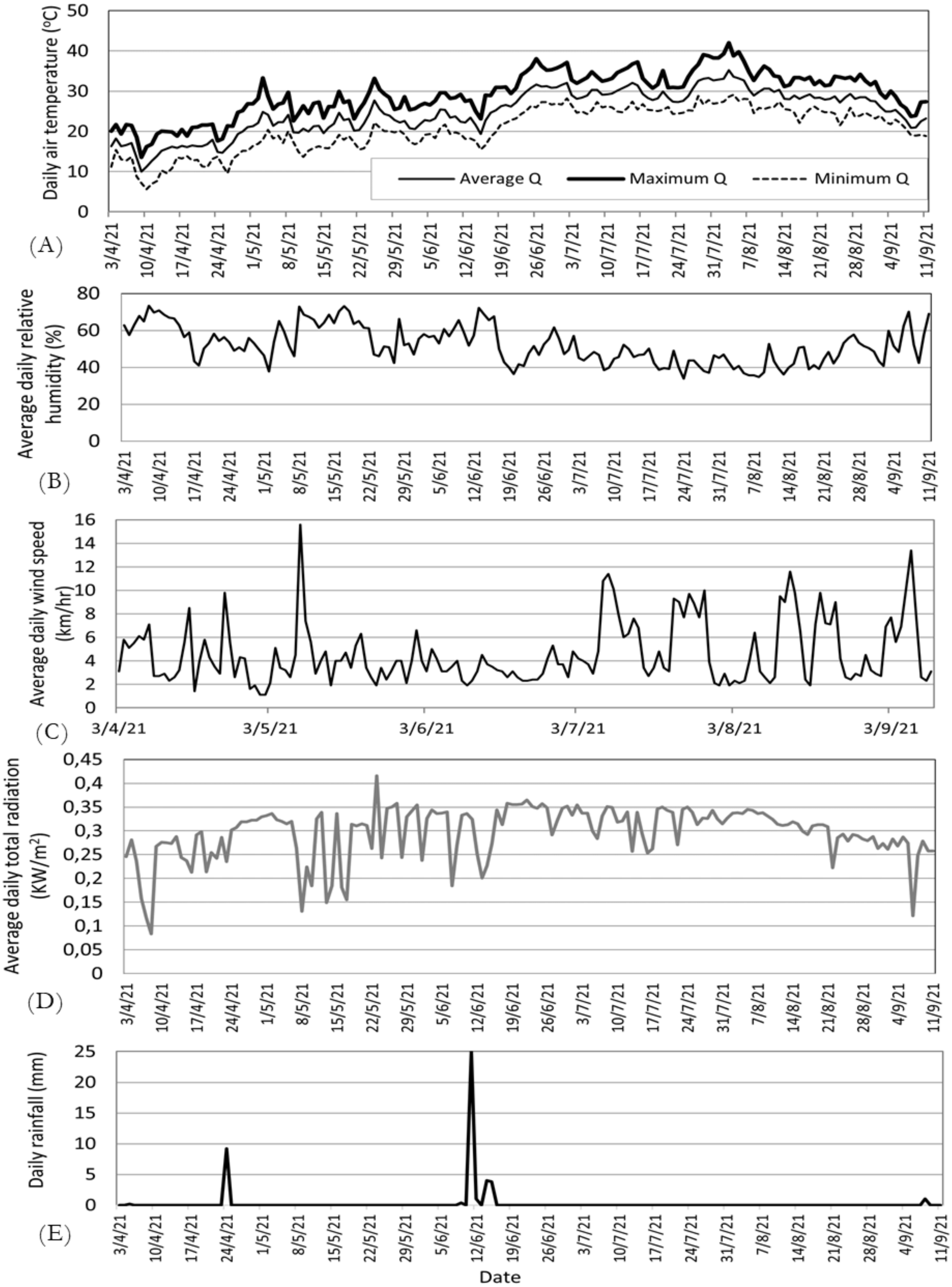


Figure 2. The average, maximum and minimum daily air temperature (A), the average daily relative humidity (B) the average daily wind speed (C), the average daily total radiation (D) and the total daily rainfall (E), during the experimental period (April 2021 – September 2021)

Plant growth evaluation

In the first week of each month the diameter and the height of all plants were recorded. The height was measured from a mark, put at the beginning of the experiment on each module at the substrate level, to the upper plant point excluding the length of inflorescence. As plant-canopy diameter (plant diameter) was recorded the average of the biggest horizontal diameter of each plant canopy and its perpendicular. In mid-June the number and length of all lateral shoots per plant was recorded. At the end of the experiment (mid-September), it was not possible to separate the root system of each plant in the container, therefore in the statistical analyses the average values of aboveground and root biomass of the two plants of each container were used. The aboveground part was cut at the soil surface and the fresh weight was immediately measured. Then it was put in the oven at 70 °C for 8 days to dry and the dry weight was measured. The root system of both plants per container was excised, rinsed under running tap water in a sieve and the fresh and dry weight was measured as above. The fraction of aboveground fresh and dry weight to root system fresh and dry weight was calculated too. The number of inflorescences was counted in July 2021 when flowering was completed.

Physiological parameters evaluation

After the 15th day of each month, one day before and one day after irrigation, the stomatal resistance (R_{leaf}), as well as the maximum quantum yield of PSII photochemistry (Φ_{PSIIo}) were measured. R_{leaf} was recorded with an AP4 Porometer (Delta-T devices) on two fully developed young leaves of each plant (the average value was recorded, i.e., n=12) from 11.00-13.00 $_{HR}$, as defined by the daily fluctuation of R_{leaf}. The Φ_{PSIIo} was recorded before sunrise, with a Photosynthesis Yield Analyzer (MINI-PAM, Portable Fluorometer, Walz, Effeltrich, Germany). One measurement per plant was taken as described by Tassoula *et al.* (2015) in eight plants of each treatment (n=8) randomly selected.

Statistical analysis

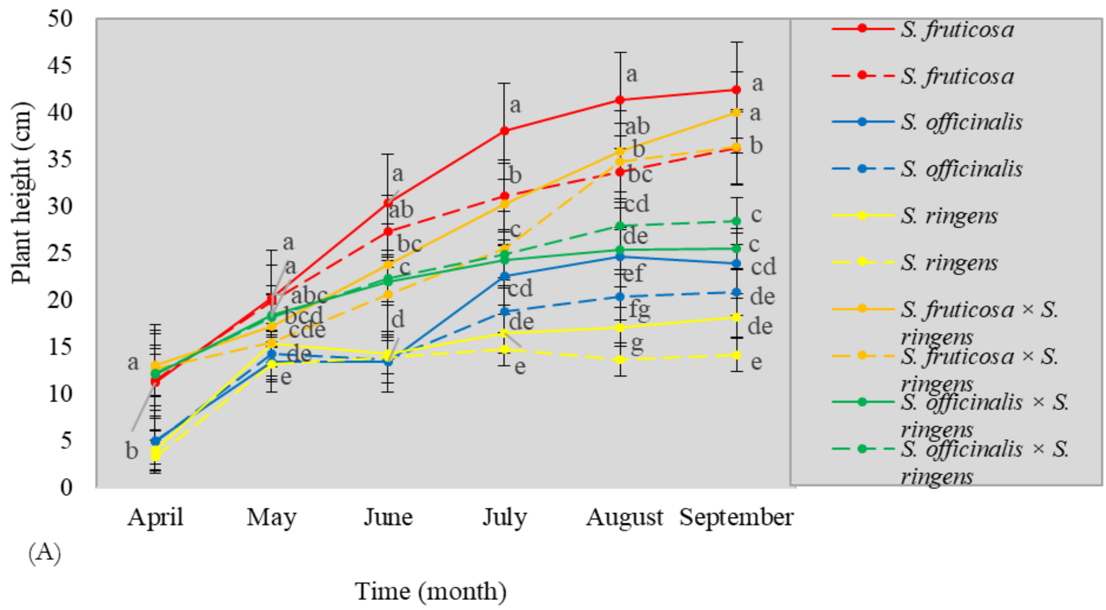
The data followed the normal distribution. The significance of the results was tested by one- or two-way analysis of variance (ANOVA) and treatment means were compared by Student's t test at $p \leq 0.05$ (JMP 13.0 software, SAS Institute Inc., Cary, NC, USA, 2013).

Results

Plant growth, flowering and plant survival

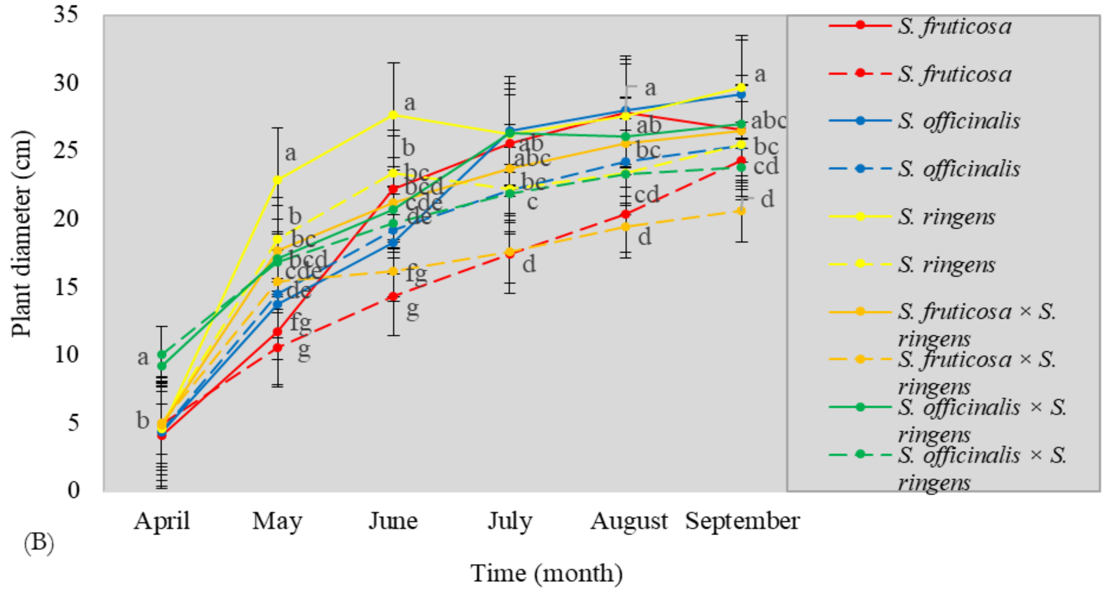
In general, all plants showed a higher growth rate at the beginning of the growing season (Figure 3A, B). Plant growth was probably promoted by the relatively low temperatures, higher relative humidity and mild winds that prevailed from April to mid-June compared to the following period, July-August, which was characterized by high temperatures and low relative humidity in combination with strong winds (Figure 2A, B, C). The highest temperatures were recorded in August, with the maximum temperature exceeding 40 °C, combined with high radiation (Figure 2A, D).

Plant height and diameter were affected by both the type of sage and the frequency of irrigation (two-way ANOVA, Figure 3A, B). *S. fruticosa* and its hybrid *S. fruticosa* × *S. ringens* grew taller than other sage types, while they were smaller in diameter, especially the hybrid under sparse irrigation, which developed the smallest diameter. To the contrary, *S. ringens* and *S. officinalis* had lower height and bigger diameter compared to the other sage types under both irrigation frequencies (Figure 3A, B).



(A)

Significance [§]	April	May	June	July	August	September
$F_{\text{plant type}}$	**	**	**	*	**	*
$F_{\text{irrigation}}$	*ns*	*	**	**	**	**
$F_{\text{interaction}}$	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
$F_{\text{one-way ANOVA}}$	**	**	**	**	**	**



(B)

Significance [§]	April	May	June	July	August	September
$F_{\text{plant type}}$	**	**	**	**	**	**
$F_{\text{irrigation}}$	*ns*	*ns*	*ns*	*	*	*ns*
$F_{\text{interaction}}$	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
$F_{\text{one-way ANOVA}}$	**	**	**	**	**	**

Figure 3. Effect of *Salvia* type and irrigation frequency, normal (full line) or sparse (dashed line) on canopy height (A) and diameter (B), during the five-month cultivation in an extensive green roof (April - September 2021)

Mean comparison in each month with Student's t test at $p \leq 0.05$. Mean values followed by the same letter do not differ. [§] NS or * or **, non-significant at $p \leq 0.05$ or significant at $p \leq 0.05$ or $p \leq 0.01$, respectively.

The factor of irrigation limited the height and diameter of the plants from May or July, respectively, to the end of the experimental period (Figure 3A, B). Focusing on the increase of plant height and diameter from the beginning to the end of the experimental period, it can be seen that they were affected by both plant type and irrigation (Table 1). The height of the plants was also affected by flowering (May-July) as *Salvia* spp. form terminal inflorescences on the shoots. *S. fruticosa* and *S. fruticosa* × *S. ringens* showed more or less continues elongation of shoots (height) up to September, as the former did not flower and the latter presented reduced flowering (Figure 4A, B), while *S. officinalis* and *S. officinalis* × *S. ringens* stopped shoot elongation in July-August and *S. ringens* practically did not elongate further since May (Figure 3A). *S. officinalis* showed shoot elongation in April-May, then the shoots developed inflorescences, which were not count in the plant height, that prevented shoot elongation, which started again in June-July from new lateral shoots (Figure 3A).

Lateral shoot number recorded in June was affected by sage type, while the total length of the laterals per plant was affected by both sage type and irrigation. Sparse irrigation resulted in a significant reduction in shoot elongation in *S. fruticosa* and *S. fruticosa* × *S. ringens* (Table 1). Both hybrids appear to have inherited shoot elongation and hence plant height from their seed-parental species, *S. fruticosa* and *S. officinalis*.

All types of sage, except *S. fruticosa,* flowered from May to July. However, only in *S. officinalis* and *S. ringens* flowered all plants, while *S. officinalis* formed the largest number of inflorescences, as almost all shoots per plant bear an inflorescence to the contrary of other sages that formed only one or two inflorescences per plant. Irrigation frequency did not have an effect on flowering (Figure 4A, B).

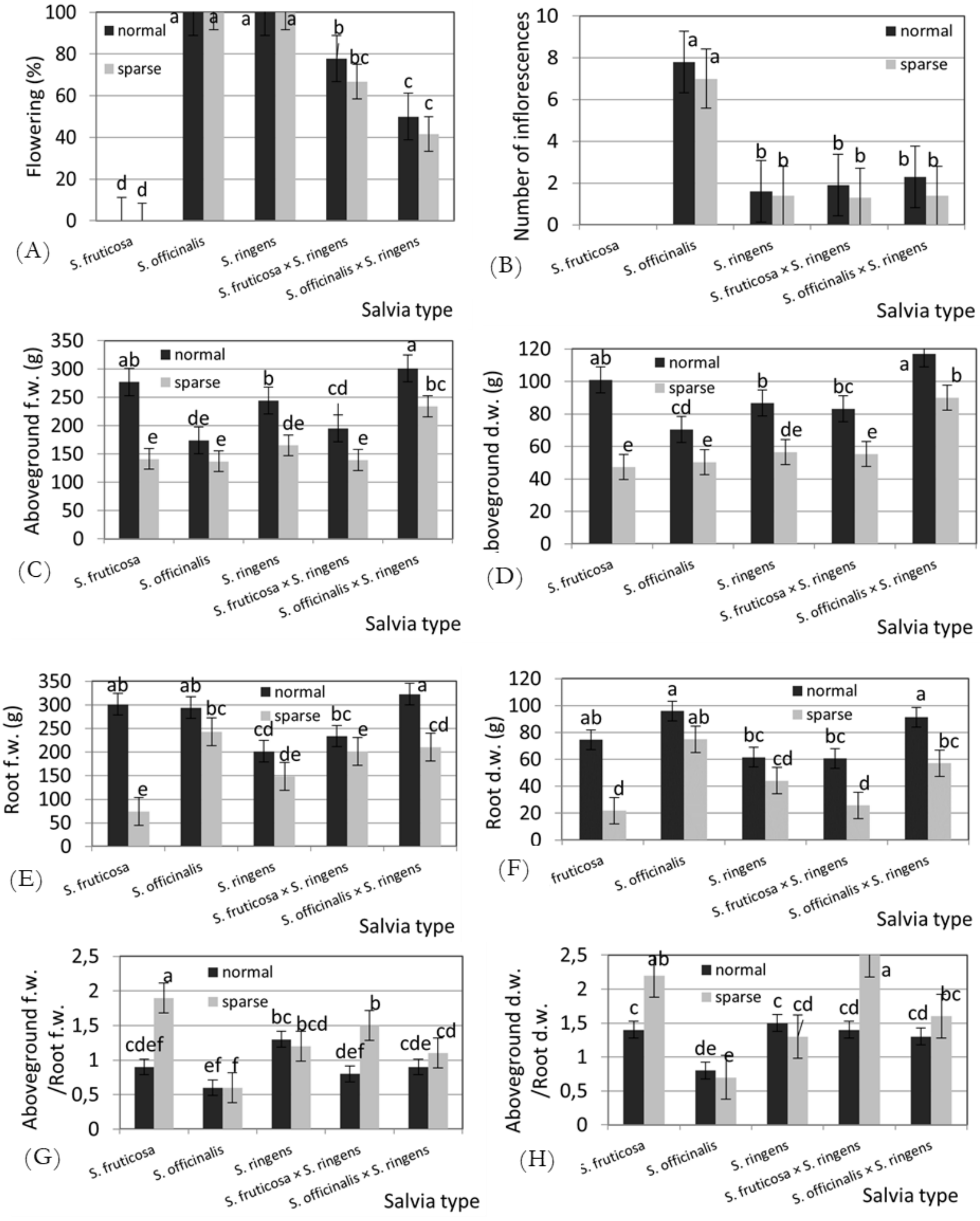
At the end of the experimental period, *S. ringens* under normal irrigation was the sage type with the highest (100%) survival rate, while *S. fruticosa* regardless of irrigation frequency and *S. fruticosa* × *S. ringens* under normal irrigation showed the lowest survival (Table 1). Mortality due to sparse irrigation was also increased in *S. ringens* and *S. officinalis*, while both hybrids under sparse irrigation had lower mortality than the parental species (Table 1).

Table 1. Plant mortality rate and canopy increase of *Salvia* spp. and interspecific hybrids shown at the end of summer 2021, five months after establishment in an extensive Mediterranean green roof, as affected by irrigation frequency, normal (n) or sparse (s). Shoot number and total shoot length were also recorded in June 2021 two months after establishment

Main factor	Mortality (%)	Final height increase (cm)	Final diameter increase (cm)	Shoot number	Total shoot Length (cm)
S. fruticosa	54.2±7.9	27.3 ± 2.2 a	21.0 ± 1.3 ab	8.2 ± 0.4 b	87.7 ± 5.0 a
S. officinalis	20.8±7.9	17.7 ± 1.6 b	22.8 ± 1.0 a	6.5 ± 0.4 c	50.4 ± 4.7 c
S. ringens	16.7±7.8	12.3 ± 1.6 c	22.9 ± 1.0 a	3.3 ± 0.4 d	25.0 ± 5.0 d
S. fruticosa × *S. ringens*	37.5±8.6	25.3± 1.9 a	19.0 ± 1.2 b	6.9 ± 0.4 c	70.8 ± 4.6 b
S. officinalis × *S. ringens*	16.7±7.8	14.7 ± 1.6 bc	15.7± 1.0 c	9.8 ± 0.4 a	88.5 ± 4.6 a
Sparse	28.3±5.0	18.3 ± 1.1 b	18.0 ± 0.7 b	6.6 ± 0.2 a	58.1 ± 3.0 b
Normal	30.0±5.7	20.7 ± 1.1 a	22.5 ± 0.7 a	7.3 ± 0.2 a	70.9 ± 3.0 a
Significance §					
$F_{\text{plant type}}$	-	**	**	**	**
$F_{\text{irrigation}}$	-	*	**	*ns*	*
$F_{\text{interaction}}$	*	*ns*	*ns*	*ns*	*ns*
$F_{\text{one-way ANOVA}}$	**	**	**	**	**
Treatment					
S. fruticosa/n	58.3 ± 13.5 a	30.3 ± 3.2 a	22.6 ± 1.9 abc	8.1 ± 0.6 bc	104.4 ± 7.5 a
S. fruticosa/s	50.0 ± 8.7 ab	24.4 ± 2.9 ab	19.3 ± 1.8 cde	8.3± 0.6 b	70.9 ± 6.8 cd
S. officinalis/n	16.7 ± 11.2 bc	18.9 ± 2.3 bc	24.7 ± 1.4 ab	6.6 ± 0.5 cd	49.7 ± 6.5ef
S. officinalis/s	25.0 ± 11.5 bc	16.5 ± 2.4 cd	20.9 ± 1.5 bcd	6.4 ± 0.6 cd	51.1 ± 6.8e
S. ringens/n	0.0 ± 0.0 c	14.1 ± 2.1 cd	25.2 ±1.3 a	3.5 ± 0.5 e	20.0 ± 6.5 g
S. ringens/s	33.3 ± 14.2 ab	10.6 ± 2.5 d	20.6 ±1.5 bcd	3.1 ± 0.6 e	30.1 ± 7.5 fg
S. fruticosa × *S. ringens*/n	58.3 ± 13.5 a	26.6 ± 3.2 ab	22.2 ±2.0 abcd	7.7 ± 0.5 bcd	84.3 ± 6.5 bc
S. fruticosa × *S. ringens*/s	16.7 ± 7.1 bc	24.0 ± 2.1 ab	15.7 ±1.3 ef	6.2 ± 0.5 d	57.4 ± 6.5 de
S. officinalis × *S. ringens*/n	16.7 ± 11.2 bc	13.5 ± 2.3 cd	17.8 ±1.4 de	10.7 ± 0.5 a	95.9 ± 6.5 ab
S. officinalis × *S. ringens*/s	16.7 ± 11.2 bc	16.0 ± 2.3 cd	13.6 ±1.4 f	9.0 ± 0.5 b	81.0 ± 6.5 bc

Mean (±SE) comparison in columns within treatments with Student's t at $p \leq 0.05$. Mean values followed by the same letter do not differ significantly at $p \leq 0.05$ by Student's t. § NS or * or **, non-significant at $p \leq 0.05$ or significant at $p \leq 0.05$ or $p \leq 0.01$, respectively.

At the end of the experimental period, the aboveground and root weight of the plants was affected by both sage type and irrigation frequency (Figure 4C, D, E, F). Sparse irrigation resulted to reduced aboveground and root fresh and dry weight (Figure 4C, D, E, F), with the largest decrease observed in *S. fruticosa*. The ratio of aboveground to root fresh and dry weight was increased under sparse irrigation in *S. fruticosa* and *S. fruticosa* × *S. ringens* (Figure 4G, H).



Significance [§]	Flowering	Inflorescences no	Aboveground f.w.	Aboveground d.w.	Root f.w.	Root d.w.	Aboveground/ Root f.w.	Aboveground/ Root d.w.
$F_{\text{plant type}}$	**	**	**	**	-	**	-	-
$F_{\text{irrigation}}$	*ns*	*ns*	**	**	-	**	-	-
$F_{\text{interaction}}$	*ns*	*ns*	*ns*	*ns*	*	*ns*	**	*
$F_{\text{one-way ANOVA}}$	**	**	**	**	**	**	**	**

Figure 4. Effect of *Salvia* type and irrigation frequency on plant flowering percentage (A), inflorescence number per plant after the completion of flowering in July 2021 (B), as well as fresh and dry weight of aboveground and root system (C, D, E, F, respectively), and aboveground/root fresh and dry weight (G, H, respectively) at the end of the experimental period (Sept. 2021)

Mean comparison with Student's *t* test at $p \le 0.05$; Mean values followed by the same letter are not significantly different at $p \le 0.05$. [§] NS or * or **, non-significant at $p \le 0.05$ or significant at $p \le 0.05$ or $p \le 0.01$, respectively.

Physiological parameters

One day before irrigation, R_{leaf} values were elevated in all sage types under sparse irrigation compared to values under normal irrigation, indicating water stress of the plants. In August, R_{leaf} values were particularly high in all plant types, while in *S. fruticosa* and the two hybrids were high even under normal irrigation program (Table 2). One day after irrigation R_{leaf} fell to much lower values (Table 3).

Φ_{PSIIo} in all plant types was not affected by irrigation frequency, with a few exceptions, i.e., *S. fruticosa, S. ringens* and *S. fruticosa* × *S. ringens* showed occasionally lower values of Φ_{PSIIo} one day before irrigation when they were irrigated sparsely (Table 4), but one day after irrigation the Φ_{PSIIo} values were returned to normal (Table 5).

Table 2. R_{leaf} one day before irrigation as affected by sage type and irrigation frequency, during the experimental period

Main factor	April	May	June	July	August
S. fruticosa	1.55 ± 0.2 bc	2.78 ± 0.6 bc	2.14 ±0.2 a	5.42 ± 0.6 a	8.87 ± 0.6 a
S. officinalis	2.26 ± 0.2a	2.61 ± 0.5 bc	1.26 ± 0.2 c	2.13 ± 0.6 c	4.51 ± 0.6 b
S. ringens	1.04 ± 0.2 c	1.62 ± 0.6 c	1.22 ± 0.2 c	3.06 ± 0.7 bc	4.55 ± 0.6 b
S. fruticosa × *S. ringens*	1.65 ± 0.2 ab	3.89 ± 0.6 ab	1.48 ± 0.2 bc	3.91 ± 0.7 abc	5.77 ± 0.6 b
S. officinalis × *S. ringens*	1.28 ± 0.2 bc	5.07 ± 0.5 a	1.85 ± 0.2 ab	4.55 ± 0.7 ab	10.42 ± 0.6 a
Normal irrigation	1.72 ±0.1	1.39 ±0.5 b	0.69 ± 0.1 b	2.26 ± 0.4 b	4.81 ± 0.4 b
Sparse irrigation	1.39 ± 0.1	4.99 ±0.5 a	2.50 ±0.1 a	5.37 ± 0.4 a	8.84 ± 0.4 a
Significance §					
$F_{plant\ type}$	**	*	**	*	**
$F_{irrigation}$	*ns*	**	**	**	**
$F_{interaction}$	*ns*	*ns*	*ns*	*ns*	*ns*
$F_{one\text{-}way\ ANOVA}$	**	**	**	**	**
Treatment					
S. fruticosa/n	1.53 ± 0.3 bcd	1.85 ± 0.8 de	0.98 ± 0.2 c	2.35 ± 0.9 d	8.20 ± 0.8 bcd
S. fruticosa/s	1.57 ± 0.3 bcd	3.70 ± 0.8 c	3.31 ± 0.3 a	8.50 ± 0.9 a	9.53 ± 0.8 b
S. officinalis/n	2.73 ± 0.3 a	0.54 ± 0.8 e	0.55 ± 0.2 c	1.82 ± 1.0 d	3.61 ± 0.9 fg
S. officinalis/s	1.79 ± 0.3 bc	4.67 ± 0.8 b	1.98 ± 0.3 b	2.43 ± 0.9 d	5.41 ± 0.8 ef
S. ringens/n	0.84 ± 0.3 d	0.85 ± 0.8 e	0.36 ± 0.2 c	2.07 ± 1.0 d	2.93 ± 0.8 g
S. ringens/s	1.24 ± 0.3 cd	2.39 ± 0.8 d	2.09 ± 0.3 b	4.06 ± 1.0 bcd	6.16 ± 0.9 de
S. fruticosa × *S. ringens*/n	2.23 ± 0.3 ab	2.79 ± 0.8 d	0.62 ± 0.2 c	2.45 ± 1.0 d	2.45 ± 0.9 g
S. fruticosa × *S. ringens*/s	1.07 ± 0.3 cd	4.99 ± 0.8 b	2.35± 0.3 b	5.36 ± 1.0 bc	9.10 ± 0.9 bc
S. officinalis × *S. ringens*/n	1.29 ± 0.3 cd	0.92 ± 0.8 ef	0.94 ±0.2 c	2.62 ± 1.0 cd	6.87± 0.9 cde
S. officinalis × *S. ringens*/s	1.28 ± 0.3 cd	9.22 ± 0.8 a	2.77 ± 0.3 ab	6.48± 1.0 ab	13.98± 0.9 a

Mean (±SE) comparison in columns within treatments with Student's t at $p \leq 0.05$. Mean values followed by the same letter do not differ significantly at $p \leq 0.05$ by Student's t. § NS or * or **, non-significant at $p \leq 0.05$ or significant at $p \leq 0.05$ or $p \leq 0.01$, respectively.

Table 3. R_{leaf} one day after irrigation as affected by sage type and irrigation frequency, during the experimental period

Main factor	April	May	June	July	August
S. fruticosa	0.85 ± 0.1 b	2.14 ± 0.6 ab	1.39 ± 0.1	1.52 ± 0.1 a	2.92 ± 0.3 b
S. officinalis	1.34 ± 0.1 a	1.83 ± 0.6 b	0.37 ± 0.1	1.83 ± 0.1 c	2.08 ± 0.3 bc
S. ringens	0.45 ± 0.1 c	0.73 ± 0.6 b	0.76 ± 0.1	1.02 ± 0.2 bc	1.87 ± 0.3 c
S. fruticosa × *S. ringens*	0.65 ± 0.1 bc	2.41 ± 0.6 ab	0.63 ± 0.1	1.43 ± 0.2 ab	2.64 ± 0.4 bc
S. officinalis × *S. ringens*	0.70 ± 0.1 bc	3.55 ± 0.6 a	1.24 ± 0.1	1.49 ± 0.2 a	4.20 ± 0.4 a
Normal irrigation	0.71 ± 0.1	1.05 ± 0.5 b	0.50 ± 0.1	1.14 ± 0.1	2.27 ± 0.2 b
Sparse irrigation	0.88 ± 0.1	3.21 ± 0.6 a	1.26 ± 0.1	1.38 ± 0.1	3.21 ± 0.2 a
Significance §					
$F_{plant\ type}$	**	*	-	*	*
$F_{irrigation}$	*ns*	*	-	*ns*	*
$F_{interaction}$	*ns*	*ns*	**	*ns*	*ns*
$F_{one\text{-}way\ ANOVA}$	**	**	**	*	**
Treatment					
S. fruticosa/n	0.63 ± 0.2 bcd	1.65 ± 0.8 bc	0.56 ± 0.1 def	1.40 ± 0.2 ab	3.51 ± 0.5 b
S. fruticosa/s	1.07 ± 0.2 ab	2.63 ± 0.8 bc	2.22± 0.2 a	1.65 ± 0.2 ab	2.34 ± 0.5 bcde
S. officinalis/n	1.38 ± 0.2 a	0.37 ± 0.8 c	0.36 ± 0.1 ef	0.99 ± 0.2 bc	1.61 ± 0.5 de
S. officinalis/s	1.30 ± 0.1 a	3.30 ± 0.8 b	0.39 ± 0.2 def	0.68 ± 0.2 c	2.55 ± 0.5 bcd
S. ringens/n	0.36 ± 0.1 d	0.47 ± 0.8 c	0.26 ±0.1 f	0.91 ± 0.2 bc	1.15 ± 0.5 e
S. ringens/s	0.54 ± 0.2 cd	0.99 ± 0.8 bc	1.25 ± 0.2 bc	1.14 ± 0.2 abc	2.59 ± 0.5 bcd
S. fruticosa × *S. ringens*/n	0.64 ± 0.2 bcd	2.35 ± 0.8 bc	0.46 ± 0.1 def	1.31 ± 0.2 bc	2.01 ± 0.5 cde
S. fruticosa × *S. ringens*/s	0.66 ± 0.2 bcd	2.46 ± 0.8 bc	0.80 ± 0.2 cde	1.55 ± 0.2 ab	3.26 ± 0.5 bc
S. officinalis × *S. ringens*/n	0.55 ± 0.2 cd	0.42 ± 0.8 c	0.81 ± 0.1 cd	1.12 ± 0.2 abc	3.09 ± 0.5 bc
S. officinalis × *S. ringens*/s	0.85 ± 0.2 bc	6.68 ± 0.8 a	1.66 ± 0.2 b	1.86 ± 0.2 a	5.32 ± 0.5 a

Mean (±SE) comparison in columns within treatments with Student's *t* at $p \leq 0.05$. Mean values followed by the same letter do not differ significantly at $p \leq 0.05$ by Student's *t*. § NS or * or **, non-significant at $p \leq 0.05$ or significant at $p \leq 0.05$ or $p \leq 0.01$, respectively.

Table 4. Φ_{PSII} one day before irrigation as affected by sage type and irrigation frequency, during the experimental period

Main factor	April	May	June	July	August
S. fruticosa	0.831 ± 8.9	0.795 ± 17.7	0.827 ± 7.8	0.822 ± 12.8	0.828 ± 10.4
S. officinalis	0.843 ± 8.9	0.827± 17.7	0.873 ± 7.8	0.834 ± 12.8	0.852 ± 10.4
S. ringens	0.840 ± 8.9	0.853 ± 17.7	0.845 ± 7.8	0.788 ± 12.8	0.826 ± 10.4
S. fruticosa × *S. ringens*	0.854 ± 8.9	0.816 ± 17.7	0.846 ± 7.8	0.820 ± 12.8	0.834 ± 10.4
S. officinalis × *S. ringens*	0.844 ± 8.9	0.844 ± 17.7	0.859 ± 7.8	0.825 ± 12.8	0.845 ± 10.4
Normal irrigation	0.848 ± 5.6	0.827 ± 11.2	0.874 ± 4.9	0.830 ± 8.1	0.836 ± 6.6
Sparse irrigation	0.837 ± 5.6	0.827 ±11.2	0.826 ± 4.9	0.806 ± 8.1	0.839 ± 6.6
Significance §					
$F_{plant\ type}$	*ns*	*ns*	-	-	*ns*
$F_{irrigation}$	*ns*	*ns*	-	-	*ns*
$F_{interaction}$	*ns*	*ns*	**	*	*ns*
$F_{one\text{-}way\ ANOVA}$	*ns*	*ns*	**	*	*ns*
Treatment					
S. fruticosa/n	0.838 ± 12.5	0.778 ± 25.1	0.862 ± 11.1 ab	0.832 ± 18.1 a	0.833 ± 14.7
S. fruticosa/s	0.824 ± 12.5	0.812 ± 25.1	0.792 ± 11.1 e	0.813 ± 18.1 a	0.823 ± 14.7

S. officinalis/n	0.853± 12.5	0.843 ± 25.1	0.883 ± 11.1 a	0.831 ± 18.1 a	0.860 ± 14.7
S. officinalis/s	0.844 ± 12.5	0.811 ± 25.1	0.863 ± 11.1 ab	0.837 ± 18.1 a	0.845 ± 14.7
S. ringens/n	0.844± 12.5	0.860 ± 25.1	0.866 ± 11.1 ab	0.849 ± 18.1 a	0.814 ± 14.7
S. ringens/s	0.836 ± 12.5	0.846 ± 25.1	0.824 ± 11.1 cd	0.727 ± 18.1 b	0.838 ± 14.7
S. fruticosa × *S. ringens*/n	0.859± 12.5	0.825± 25.1	0.892 ± 11.1 a	0.830 ± 18.1 a	0.828± 14.7
S. fruticosa × *S. ringens*/s	0.849 ± 12.5	0.807 ± 25.1	0.800 ± 11.1 de	0.811 ± 18.1 a	0.841 ± 14.7
S. officinalis × *S. ringens*/n	0.844 ± 12.5	0.829 ± 25.1	0.867 ± 11.1 ab	0.809 ± 18.1 a	0.845 ± 14.7
S. officinalis × *S. ringens*/s	0.844± 12.5	0.860 ± 25.1	0.851 ± 11.1 bc	0.841 ± 18.1 a	0.846 ± 14.7

Mean (±SE) comparison in columns within treatments with Student's *t* at $p \leq 0.05$. Mean values followed by the same letter do not differ significantly at $p \leq 0.05$ by Student's *t*. [§] NS or * or **, non-significant at $p \leq 0.05$ or significant at $p \leq 0.05$ or $p \leq 0.01$, respectively.

Table 5. Φ_{PSII} one day after irrigation as affected by sage type and irrigation frequency, during the experimental period

Main factor	April	May	June	July	August
S. fruticosa	0.862 ± 8.2 b	0.834 ± 11.8	0.882 ± 5.4	0.871 ± 9.8	0.860 ± 5.2
S. officinalis	0.874 ± 8.2 ab	0.860 ± 11.8	0.904 ± 5.4	0.872 ± 9.8	0.870 ± 5.2
S. ringens	0.863 ± 8.2 b	0.877 ± 11.8	0.885 ± 5.4	0.854 ± 9.8	0.867 ± 5.2
S. fruticosa × *S. ringens*	0.897 ± 8.2 a	0.883 ± 11.8	0.898 ± 5.4	0.884 ± 9.8	0.881 ± 5.2
S. officinalis × *S. ringens*	0.871 ± 8.2 b	0.879 ± 11.8	0.879 ± 5.4	0.862 ± 9.8	0.882 ± 5.2
Normal irrigation	0.872 ± 5.2	0.862 ± 7.5	0.891 ± 3.4	0.870 ± 6.2	0.867 ± 3.3
Sparse irrigation	0.875 ± 5.2	0.871 ± 7.5	0.888 ± 3.4	0.867 ± 6.2	0.877 ± 3.3
Significance [§]					
$F_{plant\ type}$	**	-	-	-	-
$F_{irrigation}$	*ns*	-	-	-	-
$F_{interaction}$	*ns*	*	**	*	*
$F_{one\text{-}way\ ANOVA}$	**	**	**	*	**
Treatment					
S. fruticosa/n	0.852 ± 11.6 a	0.809 ± 16.7 a	0.875 ± 7.7 d	0.868 ± 13.9 a	0.849 ± 7.3 c
S. fruticosa/s	0.872 ± 11.6 a	0.859 ± 16.7 a	0.889 ± 7.7 abcd	0.874 ± 13.9 a	0.871 ± 7.3 ab
S. officinalis/n	0.873 ± 11.6 a	0.861 ± 16.7 a	0.909 ± 7.7 a	0.870 ± 13.9 a	0.868 ± 7.3 abc
S. officinalis/s	0.876 ± 11.6 a	0.860 ± 16.7 a	0.900 ± 7.7 abc	0.875 ± 13.9 a	0.871 ± 7.3 ab
S. ringens/n	0.852 ± 11.6 a	0.879 ± 16.7 a	0.883 ± 7.7 cd	0.881 ± 13.9 a	0.865 ± 7.3 bc
S. ringens/s	0.874 ± 11.6 a	0.874 ± 16.7 a	0.888 ± 7.7 abcd	0.827 ± 13.9 a	0.869 ± 7.3 abc
S. fruticosa × *S. ringens*/n	0.905 ± 11.6 a	0.888 ± 16.7 a	0.905 ± 7.7ab	0.885 ± 13.9 a	0.879 ± 7.3 ab
S. fruticosa × *S. ringens*/s	0.888 ± 11.6 a	0.877 ± 16.7 a	0.892 ± 7.7 abcd	0.884 ± 13.9 a	0.884 ± 7.3 ab
S. officinalis × *S. ringens*/n	0.876 ± 11.6 a	0.872 ± 16.7 a	0.884 ± 7.7 bcd	0.848 ± 13.9 a	0.875 ± 7.3 ab
S. officinalis × *S. ringens*/s	0.865± 11.6 a	0.886 ± 16.7 a	0.874 ± 7.7 d	0.875 ± 13.9 a	0.888 ± 7.3 a

Mean (±SE) comparison in columns within treatments with Student's *t* at $p \leq 0.05$. Mean values followed by the same letter do not differ significantly at $p \leq 0.05$ by Student's *t*. [§] NS or * or **, non-significant at $p \leq 0.05$ or significant at $p \leq 0.05$ or $p \leq 0.01$, respectively.

Figure 5. Typical growth of aboveground and root system of *Salvia fruticosa* (A), *S. officinalis* (B), *S. ringens* (C), *S. fruticosa* × *S. ringens* (D) and *S. officinalis* × *S. ringens* (E), after five months cultivation (April - September 2021) in an extensive green roof, under normal (N) and sparse (S) irrigation.

Discussion

Evaluation of native species with limited water needs, as plants of the macchia vegetation, for use in urban extensive green roofs is a crucial parameter for sustainable urban greening in arid/semiarid Mediterranean areas (Savi *et al.*, 2016; Cáceres *et al.*, 2018). More specifically, aromatic perennial herbs with limited water needs could be ideal green roof plants to support urban biodiversity, with an emphasis on pollinators, rainwater management (Carbone *et al.*, 2015; Raimondi and Becciu, 2021) and the preservation of local character. Greek macchia vegetation is reach in aromatic herbs and an important genus represented by a number of species is *Salvia* (sage); the most known *spp.* being *S. fruticosa* and *S. officinalis.* A breeding program aimed at promoting Greek sage species in the international horticultural market and green roof industry provided two new interspecific hybrids with interesting ornamental features achieved by crossing *S. fruticosa* and *S. officinalis* with another unexplored Greek sage *S. ringens* (Figure 1).

In April 2021, *S. fruticosa*, *S. officinalis*, *S. ringens* and the *S. fruticosa* × *S. ringens* and *S. officinalis* × *S. ringens* hybrids were successfully installed in an extensive green roof in Athens Greece. Mild temperatures (10-18 °C), increased relative humidity and mild winds prevailed this month (Figure 2), which favor the growth of Mediterranean plants in green roofs. However, at the end of the summer a number of plants were dried even under the normal irrigation program. *S. fruticosa* showed the highest mortality regardless of irrigation frequency (Table 1). The longer shoots and the less compact canopy of *S. fruticosa* compared to the other species (Figure 5, Table 1) may be a reason for this, as the leaves were more exposed to the drought and windy conditions of July and August (Figure 2). The *S. fruticosa* × *S. ringens* canopy has the morphology of *S. fruticosa* (Figure 1A, D) and this hybrid also showed high mortality under normal irrigation, while under sparse irrigation it had the highest survival rate of all sage types (Table 1). *S. fruticosa* × *S. ringens* under sparse irrigation developed a smaller diameter and by the end of July a lower height also compared to plants under normal irrigation (Figure 3, 4) and this may have prevented the plants from drying in July – August period. Normally irrigated *S. ringens* plants showed 100% survival, which was though reduced by 40% under sparse irrigation to a lower level than that of its two hybrids with *S. fruticosa* and *S. officinalis*. The latter, *S. officinalis* × *S. ringens,* showed similar survival rate in both irrigation programs, resembling its parental species *S. officinalis* (Table 1). All three, *S. ringens, S. officinalis* and their hybrid, developed lower plant height compared to *S. fruticosa* and *S. fruticosa* × *S. ringens* that probably favored survival in the drought period. Furthermore, *S. fruticosa* proved to be more sensitive to surviving in the arid conditions of a Mediterranean extensive green roof compared to other native species (Kokkinou *et al.*, 2016).

Plant growth of all sage types evaluated by various growth parameters was restricted by limited irrigation (Table 1, Figure 3, 4), as previously shown for a number of macchia species grown under reduced irrigation on an extensive green roof, while growth of others was not significantly affected by reduced irrigation (Lebaschy and Sharifi ashoor abadi, 2004; Kokkinou *et al.*, 2016; Papafotiou *et al.*, 2018; Tassoula *et al.*, 2021). Sages' growth on the green roof was affected to a greater extend by reduced irrigation compared to sages plants grown under water stress in a greenhouse (Papafotiou *et al.*, 2021). Plant growth in a green roof with low substrate depth is affected by wind and heat in addition to drought and is probably affected to a greater extend by substrate temperature than the drought per se, as a high substrate temperature is an additional stress factor that affects root resistance to heat (Savi *et al.*, 2016).

S. fruticosa and *S. fruticosa* × *S. ringens* from July onwards under normal irrigation developed the highest height, which although it was reduced under sparse irrigation, especially of *S. fruticosa*, remained highest compared to the other sage types (Figure 3A). *S. officinalis* and *S. officinalis* × *S. ringens* developed average height similar to each other, which did not differ significantly in the two irrigation frequencies and *S. ringens* developed the lowest height, which was also not affected significantly by irrigation frequency (Figure 3A). In the wild, *S. officinalis* grows half the height of *S. fruticosa* (Blamey and Wilson, 1993) and *S. ringens* a quarter of the height of *S. fruticosa* (Tutin *et al.*, 1972), and these genetic traits have played a major role in plant growth in the green roof. In addition, it appears that the two hybrids, *S. officinalis* × *S. ringens* and *S. fruticosa* × *S. ringens,* inherited their height from the seed parent each, *S. officinalis* and *S. fruticosa*. The increase of plant height was inhibited in May – June due to flowering, especially in *S. officinalis* where all the shoots developed an inflorescence, except in *S. fruticosa,* which did not flower. The plants of all types were grown from apical stem cuttings excised from greenhouse-mother plants in winter. *S. fruticosa* is likely to differentiate flower buds either on last year's shoots in late summer-autumn or on shoots of sufficient length in early spring at relatively low temperatures, as in nature the species flowers from early spring in southern areas (Blamey and Wilson, 1993). The frequency of irrigation did not have a significant effect on flowering although in other plant species it has been shown that limited irrigation led to a reduced number of inflorescences (Sionit and Kramer, 1977; Descamps *et al.*, 2020).

Plant diameter at the end of summer, although limited by sparse irrigation in most sage types (Table 1, Figure 3B), was sufficient to provide acceptable substrate coverage. *S. ringens* showed the highest of all sage types horizontal growth rate at the April-May period but from June onwards the horizontal growth almost stopped and in July did not differ but only from *S. fruticosa* and *S. fruticosa* × *S. ringens* under sparse irrigation where these two types had the smallest diameter (Figure 3B). The fast horizontal growth is an advantage for a species at the establishment stage in a green roof as it reduces water losses from the substrate due to evaporation. Although tall and large plants are more effective in reducing water runoff (Nagase and Dunnett, 2012) in extensive green roofs, high plant height is not a desirable feature, because tall plants have higher maintenance requirements and risk days with strong winds. It is generally intended to use low-growing plant species that achieve substrate coverage in order to function bioclimatologically.

Under normal irrigation, *S. officinalis* × *S. ringens* hybrid developed the highest aboveground biomass but not statistically different from *S. fruticosa*, and along with *S. fruticosa* and *S. officinalis* developed the highest root biomass, too (Figure 4C, D, E, F). Restriction in irrigation led to a reduction in aboveground and root biomass of all plant types, as shown for other species as well (Zhao *et al.*, 2006; Misra and Srivastana, 2000; Toscano *et al.*, 2021). The greatest reduction of both parameters was observed in *S. fruticosa*. Under sparse irrigation *S. officinalis* × *S. ringens* had the highest aboveground biomass of all the sages, and along with *S. officinalis* the highest root biomass, too (Figure 4C, D, E, F). Restriction of irrigation induced a large increase in the aboveground/root biomass ratio in *S. fruticosa* and *S. fruticosa* × *S. ringens* while all other sages had no ratio changes. *S. officinalis* was the sage with the lowest aboveground/root biomass ratio especially under limited irrigation (Figure 4G, H), which is considered one of the parameters that ensure drought tolerance, as it optimizes water uptake (Chaves *et al.*, 2003). Root system was reported to play a key role in plant drought resistance in *S. officinalis* (Abate *et al.*, 2021), and this is supported by the present research, since *S. officinalis* showed the smallest aboveground/root biomass under both normal and sparse irrigation.

Chlorophyll a fluorescence is often used in studies on plant response and adaptation to water stress (Toscano *et al.*, 2021). A slight decrease in PSIIo values often accompanies mild water stress conditions, while severe water stress causes strong effects on the PSIIo parameter (Posch and Bennett, 2009). In the sparse irrigation program, all sage types had increased R_{leaf} values one day before an irrigation event indicating drought stress, their leaves were curled as a drought avoidance mechanism and PSIIo values were occasionally reduced statistically significantly, probably due to limited CO_2 supply in the carboxylation centers. Similarly, water stress treatments reduced the maximum quantum yield of PSII in two *Origanum vulgare* subsp. (Emrahi *et al.*, 2021). However, the values of PSIIo under water stress indicate that ΦPSII photochemistry was functional. Although under water stress the different plant species show different sensitivity, nevertheless the optimal values of PSIIo are common, i.e. 0.78-0.84 (Maxwell and Johnson, 2000). In all sage types, PSIIo values never fell below 0.78 during the experimental period, with the sole exception of *S. ringens* under sparse irrigation in

July (Table 4), indicating that photosystem II was not affected irreparably. In addition, the recovery of PSIIo values after irrigation at optimal levels indicates that no permanent photoinhibition was developed.

Conclusions

The adaptation of all sage types tested in this research in a Mediterranean extensive green roof was affected by both the plant genotype and the irrigation frequency. Both hybrids survived under water stress at higher rates compared to their parental species. Limited irrigation restricted all growth parameters, however all sage types with the exception of *S. fruticosa* and *S. fruticosa* × *S. ringens* had a satisfying growth and flowering even under limited irrigation being a good choice for a sustainable Mediterranean green roof. *S. officinalis*, *S. ringens* and *S. officinalis* × *S. ringens* hybrid are highly recommended for sustainable green roofs and xeriscaping in arid regions.

Authors' Contributions

Conceptualization: M.P., A.N.M. and L.T.; Data curation: A.N.M. and L.T.; Formal analysis: A.N.M. and L.T.; Funding acquisition: M.P.; Investigation: M.P., A.N.M. and L.T.; Methodology: M.P., A.N.M. and L.T.; Project administration: M.P.; Resources: M.P.; Supervision: M.P.; Validation: L.T., M.P. and A.N.M.; Visualization: A.N.M.; Writing - original draft; M.P., L.T. and A.N.M.; Writing - review and editing: M.P. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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