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Comparative Evaluation of *Crithmum maritimum* and *Origanum dictamnus* Cultivation on an Extensive Urban Green Roof

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Abstract: Considering that urban horticulture benefits from green roof technology, the effects of substrate type (compost-perlite-pumice 3:3:4, *v/v* and compost-perlite-pumice-soil 3:3:2:2, *v/v*) and depth (7.5 cm and 15 cm) were comparatively evaluated in the cultivation of *Crithmum maritimum* and *Origanum dictamnus* on an urban green roof in modules that included a green roof infrastructure layering. During the first cultivation period (December 2015–August 2016), plants of *C. maritimum* were taller and had greater diameter than those of *O. dictamnus*. Greater fresh and dry weights of all plant parts were observed in *C. maritimum*, as well as in the deep substrates compared to the shallow ones. During the second cultivation period (September 2016–August 2017), the growth of *O. dictamnus* surpassed that of *C. maritimum*, while plant height and foliage diameter, as well as the fresh and dry weight of all plant parts were greater in the deep substrates for both species. Conclusively, both species grew satisfactorily on an extensive urban Mediterranean green roof, while the deep substrate favored all their growth parameters. *O. dictamnus* responded better in the soil-containing substrate regarding survival, growth, and flowering, as opposed to *C. maritimum* that showed equal response in both substrate types.

Keywords: rock samphire; sea fennel; Cretan dittany; halophyte; indigenous species; edible medicinal plants; soil vs. soilless substrate; shallow vs. deep substrate; urban agriculture

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1. Introduction

Green roofs, as important components of green infrastructure planning [1,2], are artificial ecosystems that can provide nature-based solutions to problems caused to the environment by climate change and rapid urbanization, as well as improvements to human well-being, due to their multiple ecosystem services [1,3,4]. They can make life in cities safer, more sustainable and adaptive to climate change [5–8]. They also create green spaces inside urban areas, which have many advantages for the environment, ecology, and economy [8,9]. Among the benefits of green roofs are the reduction in run-off caused by urban storm water, the mitigation of the urban heat island effect, the improvement of buildings' energy efficiency, the improvement of air quality, the promotion of biodiversity, the provision of natural habitats for animals and plants, the sequestering of carbon, the reduction in urban noise, the creation of space for food production in the framework of urban agriculture, as well as aesthetic and health benefits [1,3,4,8–10].

Extensive green roofs are very hostile environments for plant growth due to extreme temperatures, radiation rates and wind exposure. Therefore, the correct selection of plant species as well as growth substrates, especially in hot and arid/semi-arid regions, such as the Eastern Mediterranean region, is of great importance for the sustainability of the green roof [11]. The use of native Mediterranean plant species, which have limited water needs, are adapted to drought stress, and present a variety of floristic characteristics, is proposed on extensive green roofs in cities with a Mediterranean climate when water shortages, biodiversity increases, and local sustainability are also taken into consideration [7,12–20]. Apart from being drought-tolerant, selected species should be heat-tolerant, since the ability to survive in harsh microclimate conditions was significantly correlated to the resistance of the root system to heat stress [21]. They should also be able to withstand wind and frost, tolerate living in poor soil, and require low maintenance [22]. Moreover, halophytes are a viable solution for landscaping salt-affected soils, as can happen on green roofs [23], or where irrigation is practiced with water of lower quality [24], as has been shown for *C. maritimum*, whose growth was not affected negatively when recycled wastewater was used for its irrigation [25]. When plants are selected for a green roof, the ecosystem services delivered by them in the urban environment should be taken into consideration, along with their survival, ornamental value, and cost [26,27]. The contribution of different plant species to CO_2 reduction and O_2 production should also be included in the plant selection process for increasing the positive environmental impact in life-cycle analysis [23]. Apart from sequestering carbon in plants and substrates, the green roofs with appropriate planting can also reduce the building's CO_2 emissions by reducing the energy consumption [28,29]. In hot periods, non-succulent canopies, especially if they are of light color and have a high leaf area index, as well as high leaf stomatal conductance, have been proven to provide the maximum insulation of the substrate and cooling of the environment, particularly when they are compared with bare substrates and succulents with thick leaves [26]. It is necessary to make comparisons among various types of plants in order to provide design guidelines regarding the selection of the most appropriate vegetative layer for a given green roof [6].

When the ornamental plants used on urban green roofs also have a commercial use, then, in addition to the environmental benefits provided by the green roof, urban agriculture is also served [14,30,31]. The rooftops of buildings in dense urban areas are unutilized spaces with direct exposure to sunlight, which could act as a useful platform for regenerating urban spaces and have immense potential to grow fresh vegetables, herbs and fruits, building food resilience, providing carbon and microclimatic benefits, and transforming rooftops into productive and interactive spaces [32,33]. Ornamental vegetables, medicinal and aromatic plant species could contribute to the planting design in urban landscapes through their aesthetic and functional quality, due to their ground-covering properties, various leaf forms, color and texture characteristics, and attractive fruit forms and colors [34]. In this context, the present study was designed, and two indigenous species, *Crithmum maritimum* and *Origanum dictamnus*, which, apart from being ornamental, have edible and medicinal value and were selected to be cultivated and comparatively evaluated in an urban extensive green roof in Athens, Greece. In this case, not only are the satisfactory growth and survival desirable, but also there is high production in the herb crop yield. Moreover, in arid/semi-arid regions, where water is a particularly precious commodity, which has been further intensified by the climate crisis, the use of water for urban greening is limited, and, therefore, exploring the possibility of utilizing drought-tolerant indigenous species in urban greenery also aims at city sustainability [30,35,36].

Crithmum maritimum L. (Apiaceae) is the only species of the genus *Crithmum* and is commonly known as sea fennel or rock samphire. It is a perennial succulent halophyte, 30–60 cm in height, with umbels of light yellow flowers from mid-summer to mid-autumn, found on the coastline of the Mediterranean and Black Sea, as well as the Atlantic coasts of Western Europe from Portugal to Southern Ireland [37–39]. It has fleshy leaves with a hot and spicy taste and a strong rhizomatous root [40]. It has been used since ancient times until present day in the human traditional diet [37,39–41], either pickled or fresh [42], as well as dried in creative gastronomy [42,43]. Its roots, leaves, and fruits are rich in several bioactive substances that exhibit antioxidant, antimicrobial [39,44–46], and insecticidal activities [47,48]. Moreover, this species is considered as one of the most promising halophytes for sustainable saline agriculture [39,49], because of its potential applications in the agri-food sector as a processed food and a source of bioactive compounds and plant protection products [49–52]. Its commercial cultivation was suggested, particularly in the economic exploitation of saline nutrient-poor settings [53].

Due to its ornamental, horizontally spreading canopy, prolonged flowering, as well as its tolerance to heat and drought, *C. maritimum* is ideal for use in extensive green roofs in arid and semi-arid areas, also serving rooftop horticulture. *C. maritimum* has shown high resistance to repeated periods of drought, due to the high capacity of its leaves to store water [54], as well as to its adaptation to the climate of the Mediterranean region and its resistance to stresses caused by climate change [40,53]. In addition, rooftop horticulture may face salinity problems [23], and, when a shallow substrate depth is used on a green roof, this may increase salt concentration from irrigation water [55], problems that can be overcome by using an halophyte. There are some studies that evaluated the growth of *C. maritimum* in greenroof systems, either alone [56] or along with other Mediterranean species [12,16,57,58], which showed that this species was suitable for Mediterranean green roofs, even with shallow substrates and low irrigation regimes. In these studies, mainly artificial substrates without soil were used [12,56–58], excepting [16], in which a substrate with soil was also tested, concluding that the soilless, lightweight, and highly porous substrates were preferable, since they led to a higher root/shoot biomass ratio in all tested species [16]. In our preliminary studies, *C. maritimum* grew better during the first four months of winter cultivation in a 15 cm deep soilless substrate rather than in a soil-containing substrate or in a shallow (7.5 cm) substrate [59]. In following experiments, we studied the growth of *C. maritimum* in the same as above substrate types at a 10 cm depth, either on the roof or at street level, in order to evaluate nutrient content and the accumulation of heavy metals in its tissues [30,60]. In these experiments, enhanced growth of the aerial parts and higher nutrient content in leaves were recorded at street level compared to the green roof, regardless of substrate type. Furthermore, cultivation on the roof or in the soilless substrate reduced concentrations of some heavy metals, making them safer for human consumption.

Origanum dictamnus L. (Lamiaceae), commonly known as the dittany of Crete, is a perennial small shrub (20–30 cm high) endemic of the Greek island of Crete, with slender arching stems and lanate leaves covered in a velvety white-gray down. It flowers in summer and autumn with small pink flowers surrounded by purple-pink bracts overlapping the calyx, and it is found on mountainous cliffs and gorges up to 1900 m above sea level [37,38]. It is referred in Greek mythology by philosophers Aristotle and Theophrastus and by the physician Hippocrates for its therapeutic properties [61,62], while several studies have shown that it has antimicrobial, anti-ulcer, and antioxidant medicinal properties [61–64], as well as antiviral activity [65]. *O. dictamnus* is classified as vulnerable and is protected by European legislation [66]. It is used as a tea plant in traditional medicine [63,67], as well as a culinary plant, as a spicy ingredient for gastronomic purposes in small quantities because of its strong flavor, and in natural beauty products [62,67]. It is cultivated commercially only by a few farmers in Crete [62,67], but its wider cultivation in semi-fertile lands throughout the Mediterranean basin is recommended [62]. Also, its use as an ornamental plant in xeriscaping and green roofs has been suggested, along with other Mediterranean species [18,19,68]. The combination of a soil substrate with normal irrigation strongly promoted its growth, despite being satisfactory with sparse irrigation and on soilless substrate as well [18]. In our preliminary studies, the substrate that contained soil also favored the plant growth of *O. dictamnus* compared to the soilless one [69]. As a plant that can be used in cities for urban agriculture as well, it was cultivated in an urban environment, where it was found that there was a lower accumulation of heavy metals when grown on a green roof than on an adjacent street [31,70].

Substrate is an important factor in the successful establishment of vegetation on a green roof, as it provides physical support to plants and nutrients and can contribute to water conservation. Precisely, the substrate depth and composition has been shown to influence the substrate moisture, since the moisture content was higher in the deeper substrate, as well as in that with the finer particles, such as clays and silts [71]. The optimum selection of the substrate is critical, because it affects plant growth and ensures the stability and longevity of the green roof, while most benefits of a green roof are directly correlated to the substrate used [8,72]. The general practice is to mix different components in growth substrates, such as natural and artificial minerals, recycled or waste materials, and organic matter, which should be stable, lightweight, provide permanent physical support for plants, contain sufficient organic minerals for plants to grow and possess a balance between free drainage, good aeration, and adequate plant water availability [8,72]. There are guidelines for substrates suitable for green roofs, e.g., FLL [73] and standards to determine substrate physical properties, such as bulk density, water permeability, and water-holding capacity, but their results may vary due to differences in sample compaction [74]. However, there is no single universal substrate for green roofs, since the choice of its components, composition, and thickness may be affected by the green roof type, climatic conditions and geographical location, cost, the availability of materials, suitability, and preference. The use of locally available ingredients could reduce the cost of their manufacturing [72]. Important parameters that should be taken into consideration during substrate selection for green roofs in different climatic regions are the mix proportions of substrate compositions, the thickness of substrate layers, the type of green roof vegetation, drought resistance, the growth contribution of substrate, storm water retention, substrate density, thermal performance, thermal conductivity, pH, salinity, and substrate nutrient content, as they may affect the lifecycle of the substrate layer and the sustainability of vegetation in green roofs to a different extent [75]. Regarding the two species studied in the present work, both have been tested in previous works of ours, as mentioned above, using the same culture system and substrate types (though only at a depth of 10 cm) on a green roof as well as at the adjacent street level [30,31,60,70]. The main objective of these studies was to determine the effect of the site of cultivation and the type of substrate on the nutrient content and the concentration of potentially toxic elements in plant tissues in order to conclude whether they are safe for human consumption. Cultivation on the green roof resulted in lower heavy metal accumulation in the leaves, while some nutrients were higher when substrate-containing soil was used [30,31,60,70]. Thus, in the present study, the cultivation took place in a green roof, using the same types of substrate, i.e., one without soil and one with soil, at two depths (7.5 cm and 15 cm), in order to evaluate, on the one hand, the yield of the plants in edible tissues, for applications in urban agriculture, and, on the other hand, comparatively, the overall development and survival of the two species for environmental benefits.

Considering that green roof technology can, on the one hand, benefit the sustainability and resilience of cities and, on the other, urban agriculture, as well as the benefits of using indigenous plant species on green roofs, and roof weight limitations, the effect of substrate type and depth on the growth and amount of herbal crop yield of *C. maritimum* and *O. dictamnus* on an extensive green roof was investigated comparatively. Thus, over two harvesting periods, the effects of (a) a soilless- versus soil-containing substrate, (b) a shallow versus deep substrate, and (c) a plant with succulent leaves and rhizomatous roots (*C. maritimum*) versus a plant with hairy leaves and shoots and fibrous roots (*O. dictamnus*) were studied on plant growth, the amount of herbal crop yield, and plant survival under the adverse conditions of an urban roof in a semi-arid region.

2. Materials and Methods

2.1. Plant Material and Cultivation Specifications

Regarding plant material, for *C. maritimum*, ten-week-old plantlets produced from rhizome cuttings and, for *O. dictamnus*, six-week-old plantlets produced from stem cuttings were used. They were planted in plastic modules measuring 40 cm × 60 cm × 22 cm in late December 2015. The planting scheme was two plants per module diagonally. A green roof infrastructure was fitted in each module, consisting of the following layering: (i) at the base of the module, moisture retention and protection of the insulation mat (type FLW-500), (ii) in the middle, a drainage layer (type Diadrain-25H), and (iii) on the top, a filter sheet (type VLF-150); all were obtained by the Landco Ltd., Diadem green roof systems, Athens, Greece. On top of the filter sheet, the substrate was added. This cultivation system has been successfully used in many of our previous green roof studies [13,14,17,18].

Regarding the cultivation site, the modules, after having been filled with the substrate, were placed on a fully exposed second-floor flat roof, at the Agricultural University of Athens (37°59001 N, 23°42019 E). The completely randomized design was followed. The experiment had three experimental factors, i.e., (i) plant species (*C. maritimum*; *O. dictamnus*), (ii) substrate type (grape marc compost–perlite–pumice 3:3:4 (*v*/*v*); grape marc compost–perlite–pumice–soil 3:3:2:2 (*v*/*v*)), and (iii) substrate depth (7.5 cm; 15 cm). Therefore, the treatments applied were eight (two plant species × two types of substrate × two depths of substrate). Twelve modules per treatment with two plants per module (i.e., 24 plants per treatment) were used (*n* values are shown in the data figures).

2.2. Substrate

Regarding substrate types, the one contained grape marc compost (C), perlite (Pe), and pumice (Pu) 3:3:4 (*v*/*v*) (CPePu or soilless substrate), and the other grape marc compost, perlite, pumice, and soil (S) 3:3:2:2 (*v*/*v*) (CPePuS or soil substrate). Regarding substrate depths, a shallow (7.5 cm) and a deeper (15 cm) depth were used. The grape marc compost was produced following the process described in [13], in the field of the Agricultural University of Athens, and it had pH and EC 6.45 and 1155 µs/cm, respectively; a diameter of perlite particles that measured 1–5 mm (Perloflor; ISOCON S.A., Athens, Greece); a diameter of pumice particles that measured 1–8 mm (LAVA Mining and Quarrying Co., Paiania, Attiki, Greece). The composition of the soil was clay (21.4%), silt (25.8%), sand (52.8%), and equivalent $CaCO_3$(21.32%). Its pH and EC were 7.9 and 241 µS/cm, respectively. The pH values of the two substrates were similar (7.5–7.6), while the EC values differed, with higher values in the soilless substrate type. Physicochemical properties of the substrates are described in detail in Table 1.

Table 1. Substrates' properties at planting.

A. Physicochemical Properties				
Substrate	**Bulk Density**	**EAW**	**pH**	**EC (µs/cm)**
CPePu	0.68	0.063	7.48	352
CPePuS	0.74	0.126	7.58	267
B. Chemical Properties				
Substrate	**N * (%)**	**P ** (mg/Kg)**	**K *** (mg/Kg)**	**Na *** (mg/Kg)**
CPePu	0.61	498.60	121.38	6.45
CPePuS	0.62	499.96	133.78	14.25

EAW: easily available water (determined from water retention curves as water released when the suction was increased from 10 to 50 cm); EC: electric conductivity; CPePu: soilless substrate; CPePuS: soil substrate; N: nitrogen; P: phosphorus; K: potassium; and Na: sodium. *: Total concentration (%); **: P-Olsen (mg/Kg); and ***: exchangeable metal forms (mg/Kg).

2.3. Irrigation

Automatic drip irrigation was applied during the warm–dry period, i.e., April–October, on the substrate surface, before sunrise, by two drippers placed at equal distances from the center of the module and the plants. The dripper supply was 4 L·h^{-1}, and the duration of irrigation was 35 and 50 min, for the shallow and deep substrate, respectively, so as to allow water drainage from the module. Plants were irrigated when substrate moisture was 17–20% v/v. Thus, irrigation was scheduled every 3 days and every 5 days, respectively, for the shallow and deep substrate, in the April–October period, excepting the mid-July–August period, when irrigation was applied every 2 and 4 days, respectively.

2.4. Meteorological Data

The meteorological data during the experimental period (January 2016 to August 2017) are presented in Figure 1. Accessing the link http://meteosearch.meteo.gr/ on 7 March 2022, information about the monthly mean, maximum and minimum air temperature, the total rainfall, and the average wind speed was found. The Laboratory of General and Agricultural Meteorology, Agricultural University of Athens, gave the data regarding the monthly average relative humidity and total radiation. Finally, the monthly total sunshine duration was found through the link http://intranet.emy.gr/emy/el/climatology/climatology, which was accessed on 30 March 2022.

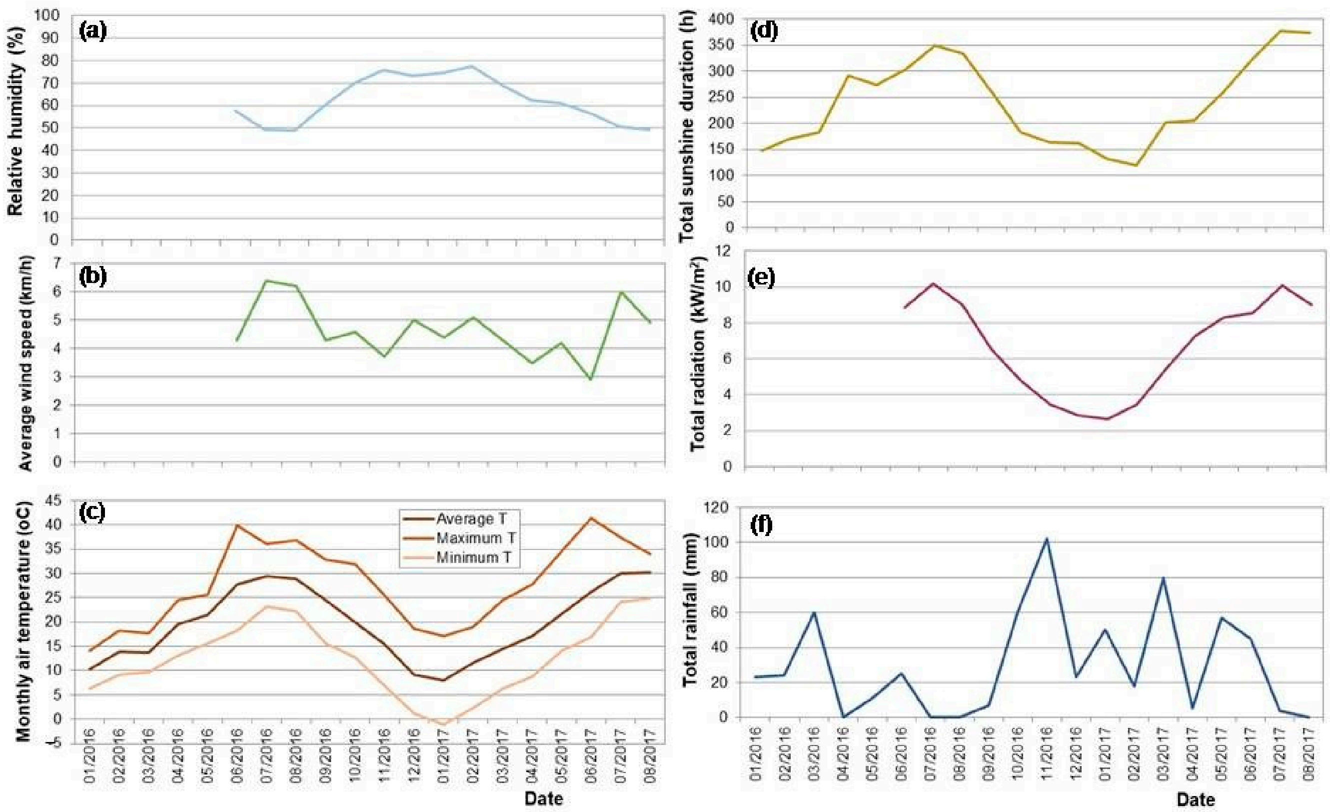


Figure 1. Meteorological data during the experimental period (January 2016 to August 2017): (**a**) average monthly relative humidity; (**b**) average monthly wind speed; (**c**) mean maximum, minimum, and average monthly air temperature; (**d**) total monthly sunshine duration; (**e**) total monthly radiation; and (**f**) total monthly rainfall.

2.5. Plant Growth Evaluation

Plant growth was recorded at the end of each month, during the cultivation period that lasted from late December 2015 until late August 2017, measuring plant height (from substrate surface to the tallest plant part), plant diameter (average value of greater horizontal diameter and its perpendicular), and the number of flowering shoots per plant. The plant canopy "growth index", which was the average of the height and the two diameters, was also calculated before and during full flowering during both years 2016 and 2017.

2.5.1. First Cultivation Period-Plant Biomass

The first cultivation period lasted from late December 2015 to late August 2016 (8 months), when plants of both species had flowered, and, then, half the plants of each treatment was harvested to record fresh and dry weights of the above-ground part and the root system. The fresh weight of the above-ground part was measured immediately after collection, while the root system was removed and rinsed under running tap water, before its fresh weight was measured. The whole root system of the two plants of each module constituted one sample because of the difficulty to separate tangled roots. The samples were then dried in a desiccator cabinet at 60 °C for 7 days, and, then, their dry weight was recorded. The ratio of root weight/above-ground weight was also calculated.

2.5.2. Second Cultivation Period-Plant Biomass

After August 2016, the remaining plants were grown for a second cultivation period, but the above-ground part and root were harvested at different times for the two species, when they are usually harvested for human consumption. Thus, the cultivation of *C. maritimum* lasted until late June 2017 (for a total of 18 months), so that the plant material would be harvested before flowering. Meanwhile, the harvest of *O. dictamnus* plant material was completed during full flowering, in late August 2017, and the cultivation lasted a total of 20 months. The procedure described in Section 2.5.1. was also followed to measure the fresh and dry weight of the above-ground part and root. The ratio of root weight/above-ground weight was also calculated.

2.6. Statistical Analysis

The data followed the normal distribution. One-, two- or three-way analysis of variance (ANOVA) was used to test the significance of the experiment, while Student's t test at $p \leq 0.05$ was used to compare treatment means (JMP 13.0 software, SAS Institute Inc., Cary, NC, USA, 2013).

3. Results

3.1. First Cultivation Period (December 2015–August 2016)

3.1.1. Monthly Growth Assessment During the First Cultivation Period

Regarding the establishment and first cultivation period, which lasted from late December 2015 to August 2016, plants of both species were successfully established, and all of them survived until the end of April 2016. However, some plant losses were observed later, mainly in the case of *O. dictamnus* cultivated in the soilless substrate, which reached 50% in the deep one (Figure 2a). At this period, the application of irrigation had just started, while air temperature had started to increase, reaching a mean maximum of 25 °C (Figure 1c). There was no rainfall in April and just 11 mm in May (Figure 1f), while the total radiation (Figure 1e) and sunshine duration (Figure 1d) were also increasing.

Both plant species showed a slow growth rate until late March 2016, but, then, their growth rate was accelerated, as expected, responding due to the increase in temperature and solar radiation (Figure 1), as well as in day length, expanding the differences in their growth ability during the first months of cultivation. *C. maritimum* could grow faster and had more developed plants than *O. dictamnus* at the end of the first cultivation period (Figures 2b,c and 3).

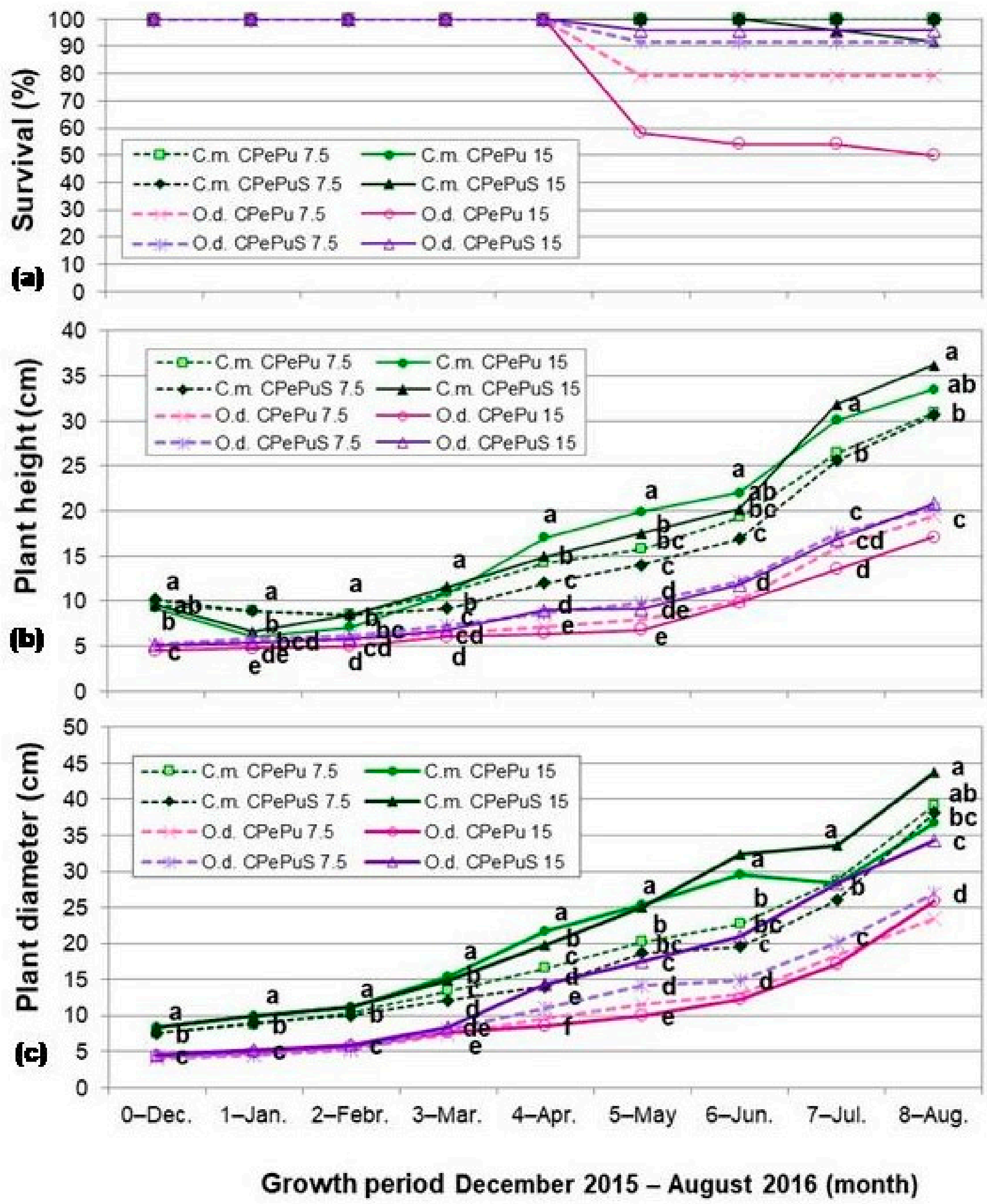


Figure 2. Comparative evaluation of the effect of substrate type and depth on monthly growth of *C. maritimum* and *O. dictamnus* in a green roof, during the first cultivation period (December 2015–August 2016): (**a**) plant survival; (**b**) plant height; and (**c**) plant diameter. Mean separation by Student's *t* test ($p \leq 0.05$) on each date (one-way ANOVA; $n = 24$). Mean values on each date followed by the same lower-case letter do not differ significantly. C.m.: *C. maritimum*; O.d.: *O. dictamnus*; CPePu: soilless substrate; CPePuS: soil substrate; 7.5: shallow substrate (7.5 cm depth); and 15: deep substrate (15 cm depth).

Three-way ANOVA of the data per month regarding plant height and diameter indicated interactions among the main factors, i.e., the type of substrate, the depth of substrate, and plant species. Thus, data per month were analyzed by one-way ANOVA. After 8 months of growth, plants of *C. maritimum* were taller than those of *O. dictamnus*, while their elongation was favored in the deep substrate (Figure 2b). Plant diameter was also greater in plants of *C. maritimum* than those of *O. dictamnus*, while both species had greater plant diameters in the deep substrate that contained soil (Figures 2c and 3).

During the first year, all plants flowered, while flowering started in July and was completed until September 2016 for both species (Figure 4a). The greatest number of flowering shoots was observed in *O. dictamnus* grown in the deep substrate with soil (Figures 3 and 4a).

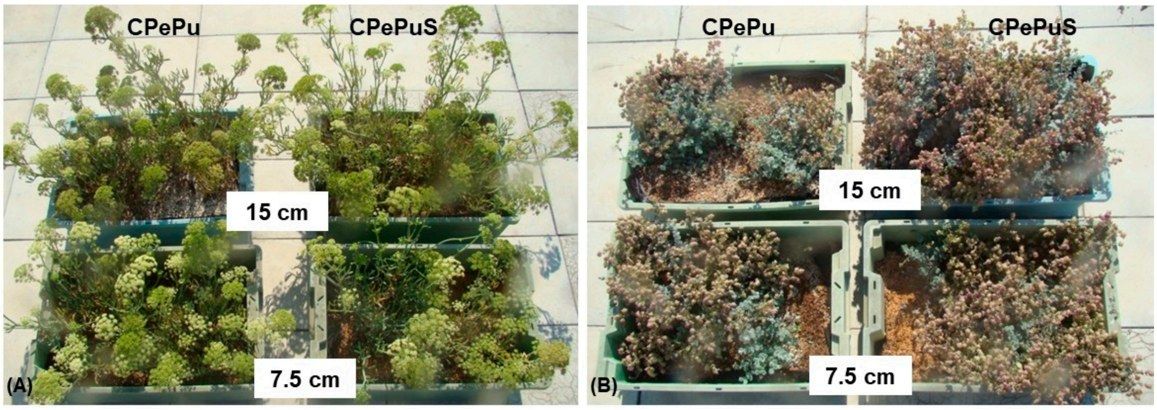


Figure 3. Typical above-ground growth and flowering of *C. maritimum* (**A**) and *O. dictamnus* (**B**) in August 2016, after eight months of growth in a green roof in the marked substrate type and depth. CPePu: soilless substrate; CPePuS: soil substrate; 7.5: shallow substrate (7.5 cm depth); and 15: deep substrate (15 cm depth).

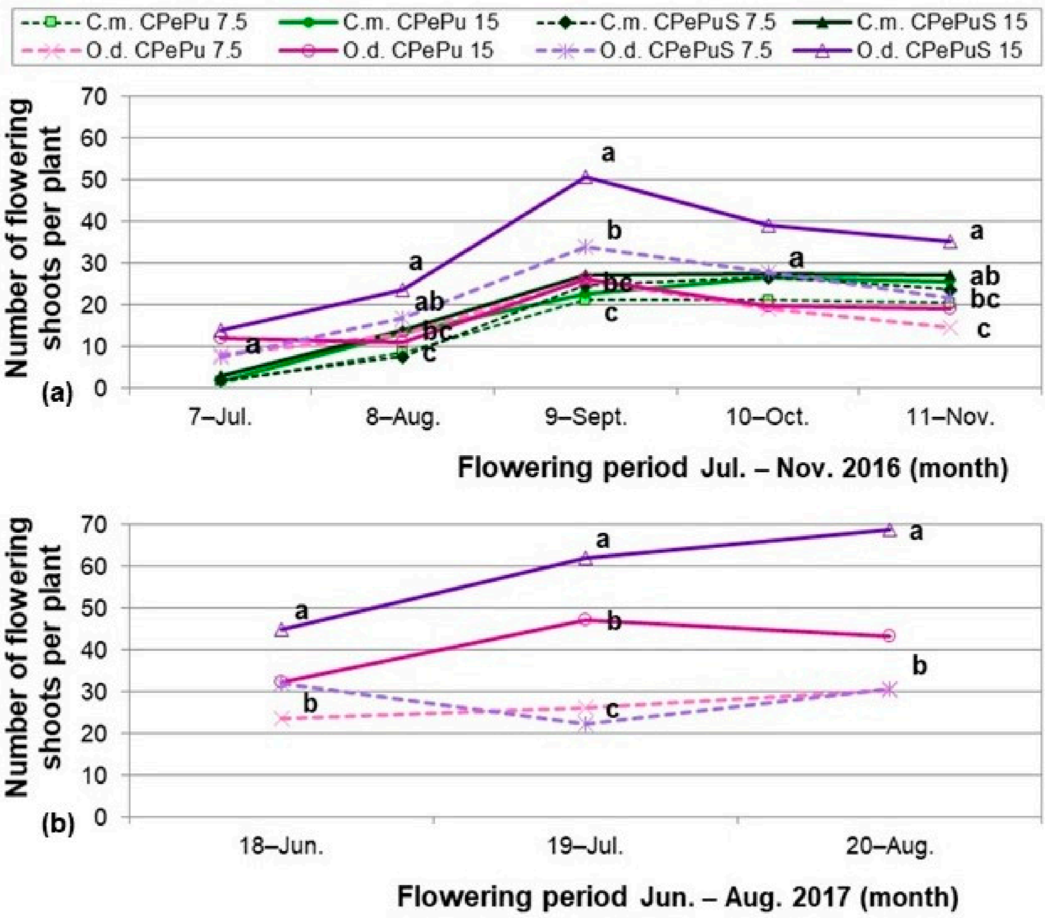


Figure 4. Number of flowering shoots per plant of *C. maritimum* and *O. dictamnus* cultivated in a green roof, as affected by the type and depth of the substrate, during (**a**) the first flowering period

(July–November 2016); and (**b**) the second flowering period (July–August 2017). Mean separation by Student's *t* test ($p \leq 0.05$) on each date (one-way ANOVA; first period, n = 11–24; second period, n = 6–12). Mean values on each date followed by the same lower-case letter do not differ significantly. C.m.: *C. maritimum*; O.d.: *O. dictamnus*; CPePu: soilless substrate; CPePuS: soil substrate; 7.5: shallow substrate (7.5 cm depth); and 15: deep substrate (15 cm depth).

3.1.2. Plant Biomass Developed in the First Cultivation Period

Half the plants of each treatment were harvested in August 2016, after 8 months of growth, and the fresh and dry weight of above-ground parts, roots, and total biomass were recorded. These data were analyzed by 3-way ANOVA. Flower fresh and dry weight were affected by the factors plant species and substrate depth, while significant interactions were observed among the three factors in the case of foliage, root, and total biomass weights (Figure 5).

The fresh and dry weight of all plant parts, as well as of total biomass, were greater in *C. maritimum* compared to *O. dictamnus*, as well as in deep substrates compared to shallow ones, especially in the case of *C. maritimum* (Figure 5). In *O. dictamnus*, the fresh and dry weights of foliage were highest in the deep soil-substrate (Figure 5b,f). In *C. maritimum*, root fresh and dry weights were highest in the deep soilless substrate (Figure 5c,g).

3.2. Second Cultivation Period (September 2016–June or August 2017)

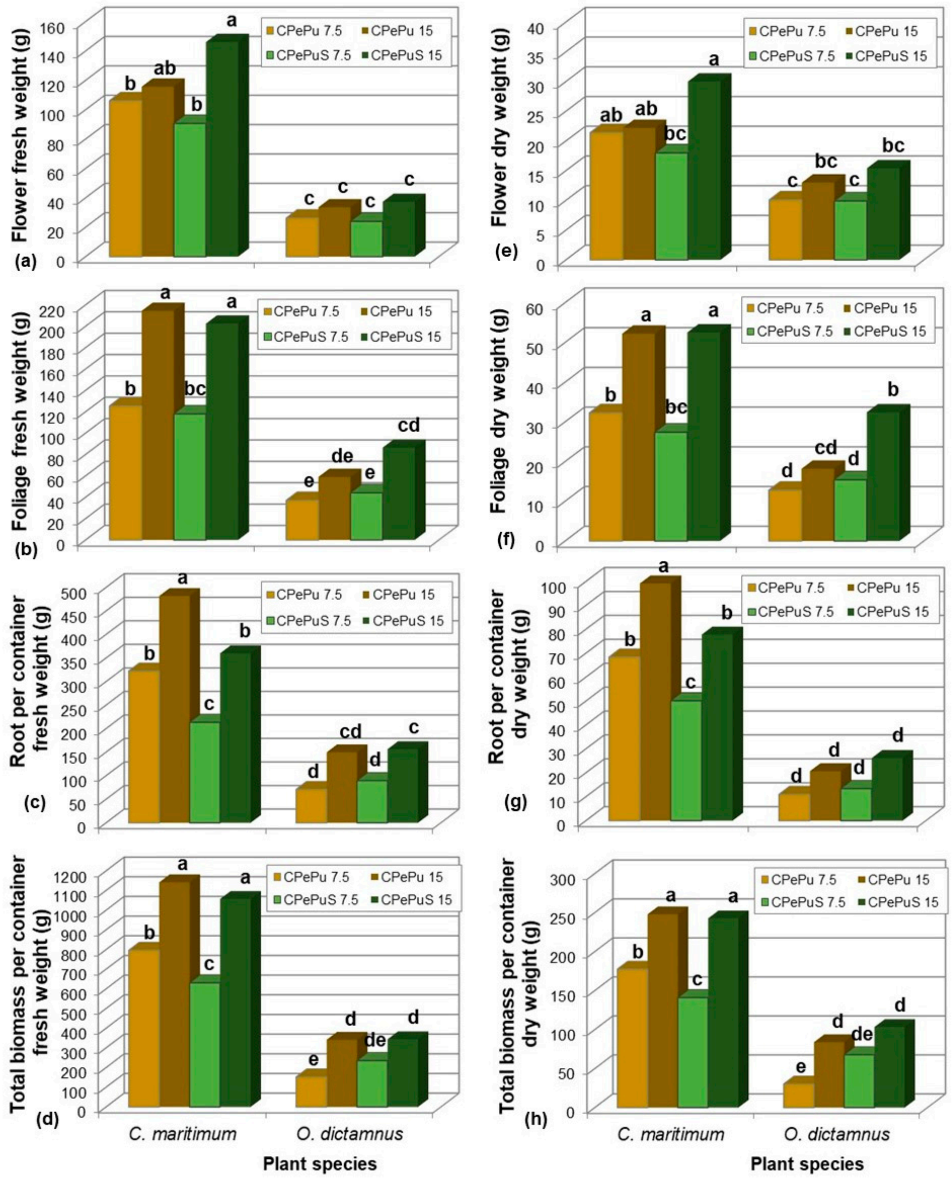
3.2.1. Monthly Growth Assessment During the Second Cultivation Period

During the second cultivation period, which lasted from September 2016 until June 2017 for *C. maritimum* and August 2017 for *O. dictamnus*, all plants survived.

Plant heights of both species showed stability from September to February 2017, when the remaining dry flower stems of *C. maritimum* were cut and removed. Thus, in March, the differences in plant height between the two species decreased so that *C. maritimum* plants in the deep soilless substrate were as tall as *O. dictamnus* plants in the deep substrate with soil, while the shortest plants were recorded in the shallow substrates for both species (Figure 6a). Then, plant height started to increase again, responding to the favorable climatic conditions, i.e., higher temperature and solar radiation (Figure 1), and, in June, plant height was affected by substrate depths that were equally higher in the deep substrates for both species (Figures 6a and 7).

In both plant species, the foliage diameter was decreasing from October to February due to the drying and falling of inflorescences but then began to increase gradually with the sprout of new vegetation (Figure 6b). In June 2017, the plant diameter of *O. dictamnus* was greater than that of *C. maritimum* in all corresponding treatments, as well as in the deep substrates compared to shallow ones. The biggest plant diameter was recorded in *O. dictamnus* cultivated in the deep substrate, especially in that with soil (Figures 6b and 7).

Only plants of *O. dictamnus* continued their growth until August, as plants of *C. maritimum* were harvested in June. From July to August, there was stability and a slight decrease in plant height and diameter (Figure 6a,b), which can be attributed to the stress experienced by the plants in June 2017, due to extremely high temperatures (Figure 1c) and the particularly strong heat wave with temperatures above 45 °C in the last week of June, which caused drying in small parts of the plants and partial leaf fall. *O. dictamnus* plants in the deep soil-substrate were the most resistant to temperature stress (Figure 7C). *C. maritimum* plants were also stressed by this heat wave, shortly before their harvest, resulting in the dehydration of its succulent leaves, especially at the shallow substrate depth (Figure 7A), but were harvested immediately after this event. At the end of the experiment, *O. dictamnus* plants were taller in the soil-containing substrate (Figure 6a) and had a larger diameter in the deep substrates (Figures 6b and 7C).



Significance § / Data	Flower F.W.	Foliage F.W.	Root F.W.	Biomass F.W.	Flower D.W.	Foliage D.W.	Root D.W.	Biomass D.W.
F substrate type	NS	NS	-	-	NS	-	-	-
F substrate depth	*	-	-	-	*	-	-	-
F species	**	-	-	-	**	-	-	-
F sub. type × sub. depth	NS	NS	NS	NS	NS	NS	NS	NS
F substrate type × species	NS	NS	**	*	NS	*	**	**
F substrate depth × species	NS	**	*	**	NS	*	*	*
F sub. type × sub depth × species	NS	NS	NS	NS	NS	NS	NS	NS
***F* one-way**	**	**	**	**	**	**	**	**

Mean separation by Student's *t* test at $p \leq 0.05$($C.m.n$ = 10–12; $O.d.n$ = 4–8; excepting roots in which n = 3–6).
Mean values in each figure followed by the same lower-case letter do not differ significantly.
§ 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. Growth of *C. maritimum* and *O. dictamnus*, after the first 8 months of cultivation (late August 2016) in a green roof, as affected by the type and depth of the substrate: (**a**,**e**): fresh and dry weight of flowers, respectively; (**b**,**f**): fresh and dry weight of foliage, respectively; (**c**,**g**): fresh and dry weight of roots per module, respectively; and (**d**,**h**): fresh and dry weight of total biomass, respectively. CPePu: soilless substrate; CPePuS: soil substrate; 7.5: shallow substrate (7.5 cm depth); and 15: deep substrate (15 cm depth).

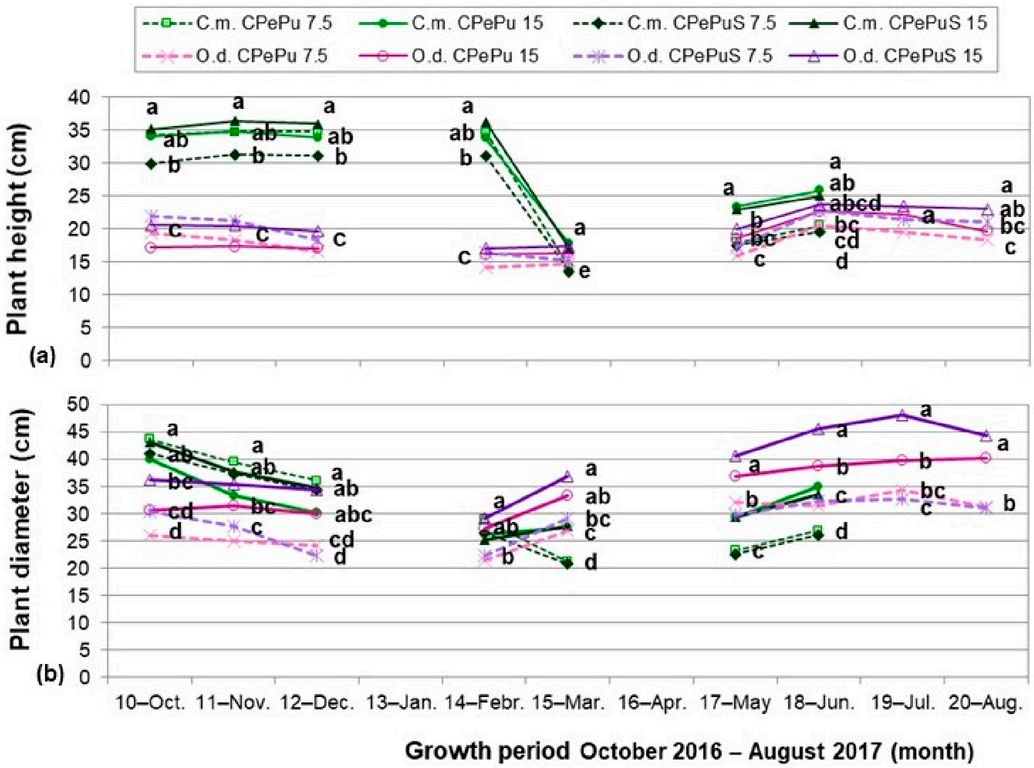


Figure 6. Comparative evaluation of the effect of substrate type and depth on the monthly growth of *C. maritimum* and *O. dictamnus* in a green roof, during the second cultivation period (October 2016–August 2017): (**a**) plant height; and (**b**) plant diameter. Mean separation on each date is determined by Student's *t* test ($p \leq 0.05$) (one-way ANOVA, n = 6–12). Mean values on each date followed by the same lower-case letter do not differ significantly. C.m.: *C. maritimum*; O.d.: *O. dictamnus*; CPePu: soilless substrate; CPePuS: soil substrate; 7.5: shallow substrate (7.5 cm depth); and 15: deep substrate (15 cm depth).

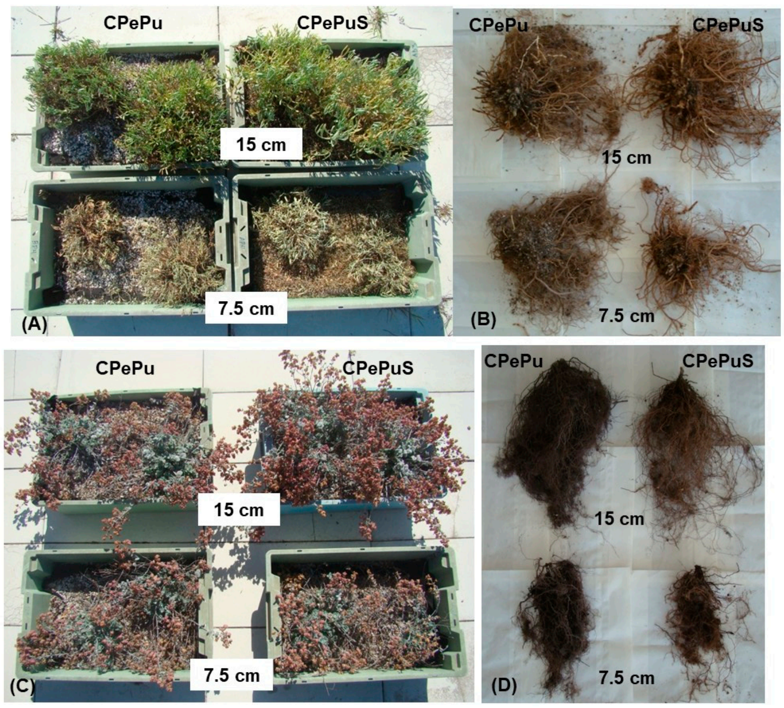


Figure 7. Typical above-ground and root system growth of *C. maritimum* (June 2017), (**A**,**B**), and *O. dictamnus*(August 2017), (**C**,**D**), respectively, cultivated in a green roof in marked substrate type and depth, for 18 and 20 months, respectively. CPePu: soilless substrate; CPePuS: soil substrate; 7.5: shallow substrate (7.5 cm depth); and 15: deep substrate (15 cm depth).

Regarding flowering, only *O. dictamnus* remained in cultivation until its full flowering (until the end of August), while *C. maritimum* was harvested earlier, as happens in the commercial cultivation of these species. The number of *O. dictamnus* flowering shoots was greatest in the deep substrate with soil as in the first cultivation period (Figures 4b and 7C).

3.2.2. Plant Biomass Developed During Both Cultivation Periods

For *C. maritimum*, the experiment was completed before flowering of the plants, in late June 2017, after a total of 18 months of cultivation, by harvesting the foliage and roots to measure their fresh and dry weight, during the harvest period of leaves for human consumption. Two-way ANOVA indicated that the fresh and dry weight of foliage, roots, and total biomass were significantly affected mainly by substrate depth, while only the fresh weight of the root was also affected by the type of substrate (Figure 8). Foliage, root, and total biomass fresh and dry weights were higher in the deep substrate (Figures 7A,B and 8), while the dry weight of the root was highest in the deep soilless substrate (Figures 7B and 8e).

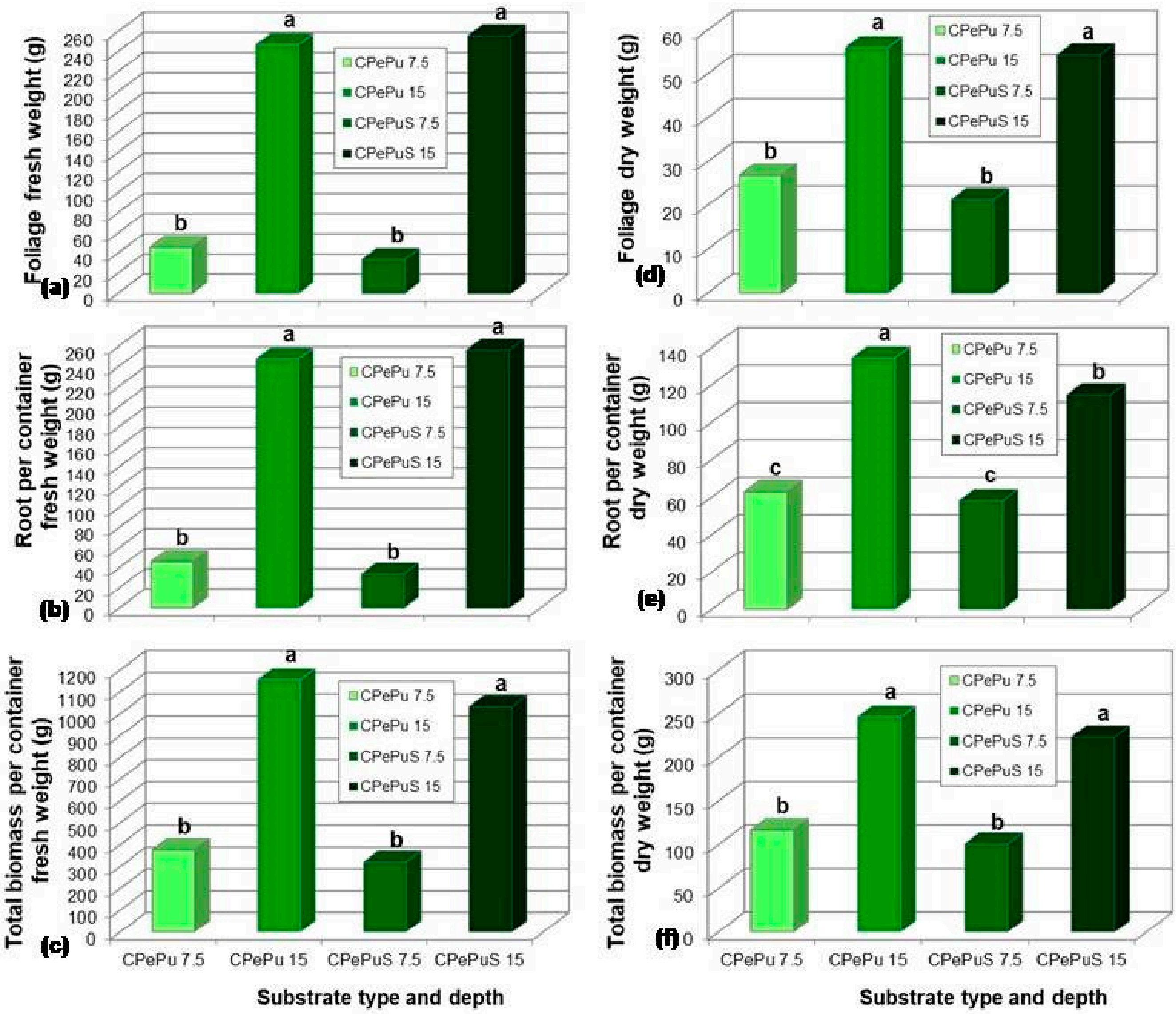
For *O. dictamnus*, the experiment was completed two months later, in late August 2017, when the plants had flowered. Fresh and dry weights of flowers and the total biomass were affected only by substrate depth, while foliage and root fresh and dry weights were affected by both substrate type and depth (Figure 9). Both flower and foliage fresh and dry weights were greater in the deep substrate that contained soil (Figures 7C and 9a,b,e,f), whereas root fresh and dry weights were greatest in the deep soilless substrate (Figures 7D and 9c,g), and total biomass fresh and dry weights were greater in the deep substrates than the shallow substrates (Figures 7C,D and 9d,h).

3.3. Foliage Growth Index Assessment

As flowering was found to make a difference in plant canopy and change the correlation between the two species, the canopy growth index (G.I.) was also calculated at important development stages, which were before and during full flowering for both years of the experiment.

In 2016, before flowering, in June, the highest G.I. was observed in *C. maritimum* grown in the deep substrates (Figure 10a). During flowering, in August, the G.I. increased for all treatments of both species, while differences among treatments in the case of *C. maritimum* decreased (Figure 10b). During the first year, the G.I. of *C. maritimum* was almost twice that of *O. dictamnus* (Figure 10a,b).

In 2017, before flowering, in June, the G.I. of *O. dictamnus* surpassed that of *C. maritimum* in corresponding treatments, the G.I. was higher in deep substrates compared to shallow ones for both *O. dictamnus* and *C. maritimum*, and the highest G.I. was recorded for *O. dictamnus* cultivated in the deep substrate with soil (Figure 10c). As *C. maritimum* was harvested in late June before flowering, growth indices at flowering, in late August, were calculated only for *O. dictamnus,* which revealed that *O. dictamnus* plants in July and August 2017, in contrast to the same period in 2016, did not appear to increase the G.I. (Figure 10d). This pause in growth can be attributed to the severe summer heat wave in 2017 as mentioned above.

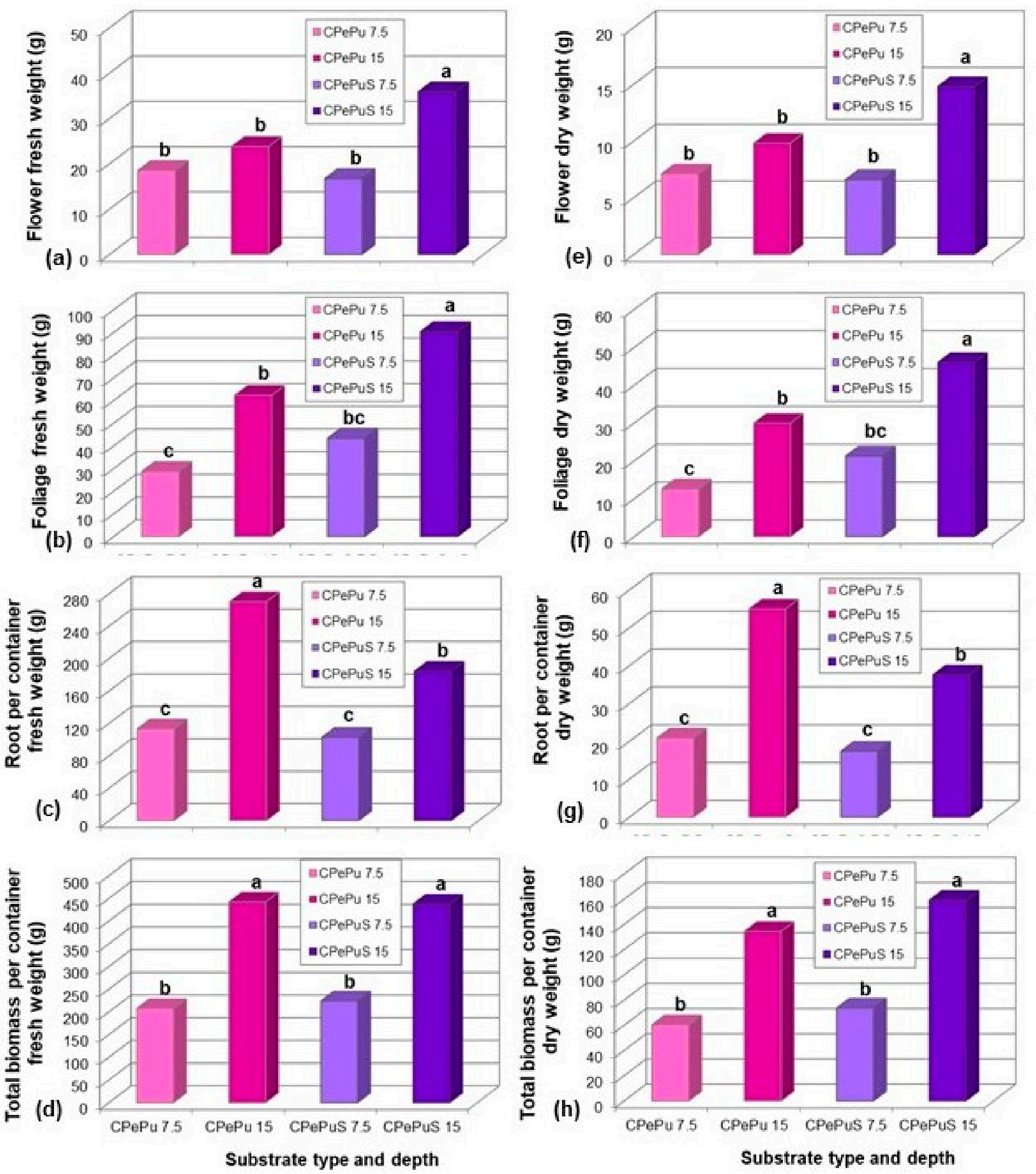


Significance § Data	Foliage F.W.	Root F.W.	Biomass F.W.	Foliage D.W.	Root D.W.	Biomass D.W.
*F*substrate type	NS	**	NS	NS	NS	NS
F substrate depth	**	**	**	**	**	**
*F*sub. type × sub. depth	NS	NS	NS	NS	NS	NS
***F* one-way**	**	**	**	**	**	**

Mean separation by Student's *t* test $p \leq 0.05$ (foliage $n = 12$; roots $n = 6$). Mean values in each figure followed by the same lower-case letter do not differ significantly.

§ NS or **, non-significant at $p \leq 0.05$ or significant at $p \leq 0.01$, respectively.

Figure 8. Growth of *C. maritimum* as affected by substrate type and depth after cultivation for a total of18 months (June 2017) in a green roof:(**a**,**d**): foliage fresh and dry weight, respectively; (**b**,**e**): fresh and dry weight of roots per module, respectively; and (**c**,**f**): total biomass fresh and dry weight, respectively. CPePu: soilless substrate; CPePuS: soil substrate; 7.5: shallow substrate (7.5 cm depth); and 15: deep substrate (15 cm depth).

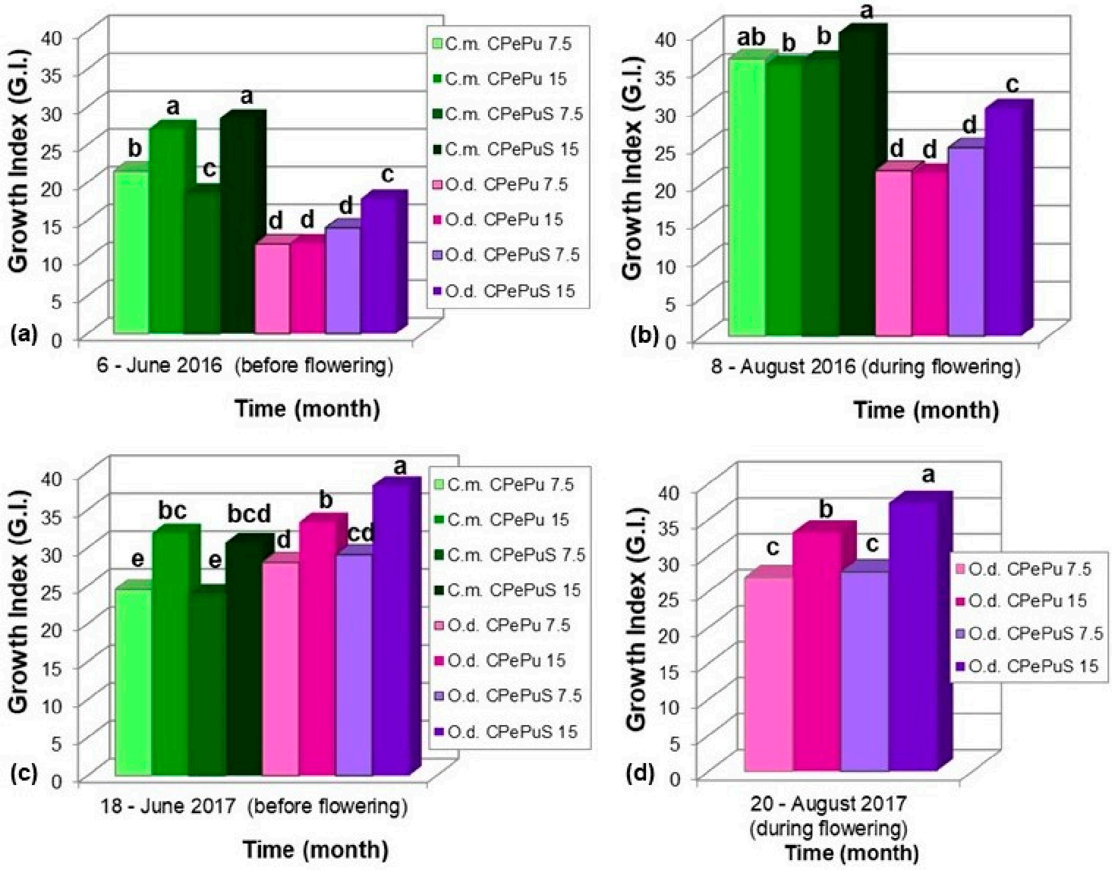


Significance [§] / Data	Flower F.W.	Foliage F.W.	Root F.W.	Biomass F.W.	Flower D.W.	Foliage D.W.	Root D.W.	Biomass D.W.
F sub. type	NS	**	*	NS	NS	**	*	NS
F sub. depth	**	**	**	**	**	**	**	**
F sub. type × sub. depth	NS	NS	NS	NS	NS	NS	NS	NS
***F* one-way**	**	**	**	**	**	**	**	**

Mean separation by Student's *t* test at $p \leq 0.05$ (n = 6–12; excepting roots n = 3–6). Mean values in each figure followed by the same lower-case letter do not differ significantly.

[§] NS or * or **, non-significant at $p \leq 0.05$ or significant at $p \leq 0.05$ or $p \leq 0.01$, respectively.

Figure 9. Effect of substrate type and depth on the growth of *O. dictamnus*, after cultivation for a total of 20 months (August 2017), in modules with fitted green roof infrastructure: (**a**,**e**): flower fresh and dry weight, respectively; (**b**,**f**): foliage fresh and dry weight, respectively; (**c**,**g**): roots per module fresh and dry weight, respectively; and (**d**,**h**): total biomass fresh and dry weight, respectively. CPePu: soilless substrate; CPePuS: soil substrate; 7.5: shallow substrate (7.5 cm depth); and 15: deep substrate (15 cm depth).



Significance § / Data	G.I. June 2016	G.I. August 2016	G.I. June 2017	G.I. August 2016
F sub. type	-	-	-	NS
F sub. depth	-	-	**	**
F species	-	**	-	-
F sub. type × sub. depth	**	*	NS	NS
F sub. type × species	**	NS	*	-
F sub. depth × species	**	NS	NS	-
F sub. type × sub. depth × species	NS	NS	NS	-
***F* one-way**	**	**	**	**

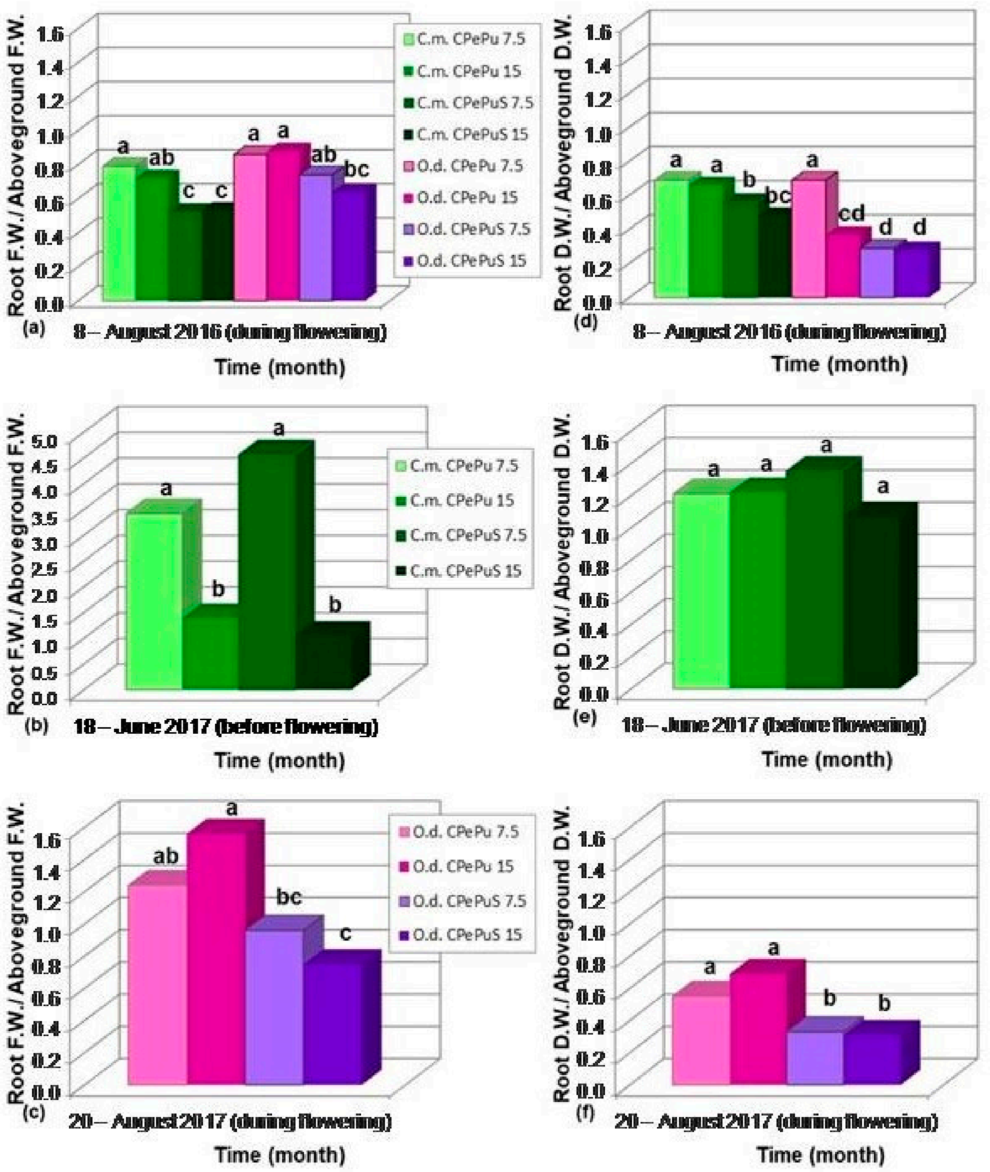
Mean comparison by Student's *t* test at $p \leq 0.05$ (first cultivation period 2016, $n = 10$–24; second cultivation period 2017 $n = 6$–12). Mean values in each figure followed by the same lower-case letter do not differ significantly.
§ NS or * or **, non-significant at $p \leq 0.05$ or significant at $p \leq 0.05$ or $p \leq 0.01$, respectively.

Figure 10. The plant canopy growth index* of *C. maritimum* and *O. dictamnus*, as affected by the type and depth of the substrate, after cultivation in a green roof for periods depending on the flowering time of each species: (**a**) cultivation for 6 months, before the first flowering period (June 2016); (**b**) cultivation for 8 months, during the first flowering (August 2016); (**c**) cultivation for 18 months, before the second flowering period (June 2017); and (**d**) cultivation of only *O. dictamnus* for 20 months, during the second flowering period (August 2017). C.m.: *C. maritimum*; O.d.: *O. dictamnus*; CPePu: soilless substrate; CPePuS: soil substrate; 7.5: shallow substrate (7.5 cm depth); and 15: deep substrate (15 cm depth). * Growth index = (plant height + diameter 1-greater horizontal diameter + diameter 2-perpendicular of diameter 1)/3.

3.4. Root/Above-Ground Biomass Assessment

As the development of the root system in relation to the development of the above-ground parts of plants may affect their establishment and resistance to abiotic parameters, such as drought and heat, the ratio of root biomass/above-ground biomass was also calculated at important developmental stages, when the plants were harvested to record fresh and dry weights.

After eight months of cultivation, higher ratios of root/above-ground biomass were recorded in the soilless substrate compared to that with soil for both species, irrespective of substrate depth (Figure 11a,d). In the case of *O. dictamnus*, cultivated in the soilless shallow substrate, the ratio of root/above-ground biomass was equal to the ratio recorded in the corresponding treatment of *C. maritimum* (Figure 11d), while, in the other treatments, lower ratios of root/above-ground biomass were recorded in *O. dictamnus* compared to *C. maritimum*.



Significance § / Data	R f.w./AG f.w. Aug. 2016	R d.w./AG d.w. Aug. 2016	R f.w./AG f.w. June 2017	R d.w./AG d.w. June 2017	R f.w./AG f.w. Aug. 2017	R d.w./AG d.w. Aug. 2017
F sub. type	**	-	NS	NS	**	**
F sub. depth	NS	-	**	NS	NS	NS
F species	**	-	NS	NS	NS	NS
F sub. type × depth	NS	**				
F sub. type × species	NS	*				
F sub. depth × species	NS	*				
F sub. type × depth × sp.	NS	**				
***F* one-way**	**	**	**	NS	**	**

Mean comparison by Student's *t* test at $p \leq 0.05$ (n = 3–6). Mean values in each figure followed by the same lower-case letter do not differ significantly.

§ NS or * or **, non-significant at $p \leq 0.05$ or significant at $p \leq 0.05$ or $p \leq 0.01$, respectively.

Figure 11. Effect of substrate type and depth on root (R)/above-ground (AG), fresh (f.w.), and dry (d.w.) weight per module of *C. maritimum* and *O. dictamnus*, after cultivation in a green roof for different periods:

the fresh (**a**) and dry (**d**) R/AG ratio for both species at the end of the first cultivation period (during flowering, late August 2016); the fresh (**b**) and dry (**e**) R/AG ratio for *C. maritimum*, before the second flowering period (late June 2017); and the fresh (**c**) and dry (**f**) R/AG ratio for *O. dictamnus*, during the second flowering period (late August 2017). C.m.: *C. maritimum*; O.d.: *O. dictamnus*; CPePu: soilless substrate; CPePuS: soil substrate; 7.5: shallow substrate (7.5 cm depth); and 15: deep substrate (15 cm depth).

After 18 months of cultivation, when only *C. maritimum* was harvested, the ratios of root/above-ground fresh weight were extremely higher in the shallow substrates than in the deep ones, irrespective of substrate type (Figure 11b), while no differences among treatments were found in the ratio root/above-ground dry weights (Figure 11e). This can be explained by the fact that above-ground parts of the plants in the shallow substrates were severely dehydrated before their harvest, due to the heat wave they suffered at the end of June 2017, while their roots were less affected being protected inside the substrate.

After 20 months of cultivation, when *O. dictamnus* plants were harvested, root/above-ground biomass ratios were higher in the shallow substrates compared to deep ones, regardless of substrate type (Figure 11c,f).

4. Discussion

The comparative evaluation of growth of *C. maritimum* and *O. dictamnus* cultivated on an extensive green roof showed that all three experimental factors (substrate type, substrate depth, plant species) affected, to a lesser or greater extent, some of the growth parameters studied. The effect of the experimental factors was evident both during the monthly recording of the growth of the plants and when they were harvested either during full flowering (late August 2016) or during the growth stage when each is harvested for human consumption (late June 2017 for *C. maritimum*, late August 2017 for *O. dictamnus*).

4.1. Effect of Substrate Type

Comparing the two species as regards their response to substrate type, *O. dictamnus* was benefited by the substrate that contained soil regarding survival, growth, and flowering, as opposed to *C. maritimum* that showed equal response in both substrate types.

The establishment and first growth of *O. dictamnus* were greatly affected by substrate type, since considerable losses were recorded in the soilless substrate during May 2016, ranging from 20% to 50%, at the highest percentage in the deep substrate. It is probable that the root system of the 4 to 5-month old *O. dictamnus* plants did not develop sufficiently in the soilless substrate, in order to reach stored water at the base (green roof infrastructure) of the module, which, in combination with less water retained in the soilless substrate and the more demanding climatic conditions of late spring, stressed the plants and resulted in their loss. The choice of the appropriate substrate can determine the success of green roof installations in arid environments, especially if species with different water requirements are employed, since water status is significantly affected by the substrate type [11].

At the end of the first year of cultivation, both *C. maritimum* and *O. dictamnus* had the largest foliage diameter in the deep substrate that contained soil compared to other treatments for each species. However, at low substrate depth, in both species, the soil did not promote plant growth, and, in *C. maritimum*, it inhibited root growth and, consequently, total plant biomass. At the end of the second year of cultivation, *O. dictamnus* in the deep substrate with soil had the greatest foliage diameter of all treatments, whereas the growth of *C. maritimum* was equal in both substrate types. During the establishment period in a green roof, *O. dictamnus* plant diameter growth was also shown to be favored by a soil substrate [69,76], whereas *C. maritimum* responded better in the soilless one [59]. As cultivation was proceeding, *O. dictamnus* continued to benefit from the substrate with soil [31,70], while the growth of *C. maritimum* was not affected by substrate type [30,60]. Similarly, faster growth in the first months of their cultivation on an urban extensive green roof was observed for *Convonvulus cneorum* and *Sideritis athoa* when the substrate contained soil, whereas plant diameter was not affected by the substrate type at the end of the second dry period [76].

Considering the equal growth of *C. maritimum* on both substrates in the long term, as well as the generally satisfactory growth of *O. dictamnus* in the soilless type, despite its superior growth in the soil type, the substrate without soil could be recommended for cultivation in the green roof of both species with the aim of achieving a low construction weight. This is in accordance with previous studies on *C. maritimum* [16,56,57] and *O. dictamnus* [18,69,70] or other Mediterranean xerophytes [14,16,57], in which the recommended substrates for green roof cultivation were lightweight, highly porous, and soil-free.

4.2. Effect of Substrate Depth

Substrate depth significantly affected all growth parameters of both plant species, as well as their survival either during the first growth or after the heat stress that they suffered in June 2017.

As already mentioned above, in the case of *O. dictamnus*, at the end of the first spring period of culture, more plants were lost in the deep soilless substrate compared to the corresponding shallow one. This probably indicates that the root system of young *O. dictamnus* plants did not develop enough in the soilless substrate to reach stored water at the base of the module, particularly in the deep substrate.

At the end of the experiment, plants of both species were taller and had a greater foliage diameter and canopy growth index in the deep substrates compared to the shallow ones. Similarly, fresh and dry weights of flowers, foliage, and roots were all greater in the deep substrates. The favorable effect of substrate depth on the plant growth of *C. maritimum* and *O. dictamnus* had already been shown from the first months of the establishment period [59,69], while it has also been reported in previous works on these species [19,56], as well as for other indigenous Mediterranean xerophytes, such as *Dianthus fruticosus* [77], *Artemisia absinthium*, *Helichrysumorientale*, and *H. italicum* [13], as well as *Salvia fruticosa* [20] and *Lavandula angustifolia* [78]. Enhanced flowering in deeper substrates has also been shown for several indigenous Mediterranean plants grown in urban extensive green roofs [19,20]. However, as in this study, although increased substrate depth favored plant growth, growth was also satisfactory in the shallow substrates.

Plants of both species proved more resistant to the temperature stress experienced by a heat wave in late June 2017 when grown in deep substrates. Improved survival in deeper substrates has been shown for several species [20,79,80], while the tolerance of *L. angustifolia* to harsh summer conditions also improved in the deeper substrate of 30 cm [78]. This could be due to the larger and more extensive root system that, as we found in the present study, developed in the deep substrates, which makes more efficient use of the stored water at the base of the module, or that the stored water can evaporate faster from the shallow substrate than from the deep one. Brown and Lundholm [79] suggested that substrate depth exerted influence over plant communities via drought, since there was the greatest change in the plant community after the driest year of their study. At the same time, the shallow substrate can be heated more than the deep one, thus hindering the proper functioning of the roots [14,21]. According to Savi et al. [21], plant survival can be affected to a larger extent by high substrate temperature than drought per se. Aiming to limit weight and installation costs, the depth of the substrate is reduced in green roof research [81], although such a strategy might contrast with the need to minimize temperature extremes in the substrate and assure plant survival.

4.3. Effect of Plant Species

The plant species selected for this study are proposed for use both as ornamentals and for urban agriculture and possess certain morphological characteristics that merit comparative examination in order to assess their ability to be grown on sustainable urban green roofs. *C. maritimum* was selected due to its succulent leaves and rhizomatous roots, while *O. dictamnus* due to its densely hairy leaves and shoots and fibrous roots. The same species were also used in a parallel experiment, in the same substrate types, at a 10 cm depth, in the roof and at the street level, aiming to investigate their growth and, mainly, the accumulation of potential toxic elements in their tissues [30,31,60,70]. The difference in their leaf morphology affected heavy metal accumulation, which was found in higher concentrations in *O. dictamnus* leaves. Also, leaf washing to reduce the concentration of heavy metals was ineffective in the case of *C. maritimum*, probably because less dust and environmental air pollutants were held on its smooth leaves compared to the highly hairy leaves of *O. dictamnus* [30,31].

In the present study, *C. maritimum* and *O. dictamnus* were found to differ in their growth rhythm during the two periods of cultivation. During the first period (December 2015–August 2016), plants of *C. maritimum*, in all treatments, grew faster than plants of *O. dictamnus*, so that, after eight months of cultivation, plants of *C. maritimum* were taller, had a greater foliage diameter and plant canopy growth index (almost double that of *O. dictamnus*), as well as fresh and dry weights of all plant parts compared to *O. dictamnus*. Our previous research showed that there were no differences between the two studied species regarding their tissue N, P, and K content, except, perhaps, that the roots of *C. maritimum* contained less N than its leaves [30], as well as from all plant tissues of *O. dictamnus* [31]. Thus, it is possible that the higher root/above-ground dry biomass ratio that we observed in *C. maritimum* compared to *O. dictamnus*, as well as the adaptive mechanism of *C. maritimum* to tolerate the nutrient limitations and perform better under less fertile conditions [82] gave this species a better establishment and subsequently faster growth compared to *O. dictamnus*. Photosynthetic activity of the leaves may have also been affected by the leaf morphology of each species. In winter and spring, the ΦPSIIo in *O. dictamnus, C. cneorum*, and *S. athoa* had the lowest values compared to other seasons, while, in *A. halimus* and *L. cretica*, the values measured in winter were at the highest range [18].

During the second period (September 2016–June or August 2017), before flowering, the growth of *O. dictamnus* surpassed that of *C. maritimum*, since they were both equally tall, while *O. dictamnus* had a greater diameter and canopy growth index in all corresponding treatments. However, looking at the plants' biomass, during the first cultivation period, *C. maritimum* clearly produced much larger biomass (dry weight) than *O. dictamnus*, and, again, during the second cultivation period, the total biomass of *C. maritimum* was much greater than that of *O. dictamnus*, but this difference was mainly due to the increased biomass of the *C. maritimum* rooting system rather than the biomass of the above-ground part. The increased biomass of *C. maritimum* makes it ideal for use in urban environments regarding its contribution to the reduction in atmospheric CO_2, as the selection of vegetation is an important parameter in order to sequester higher amounts of CO_2 by a green roof. According to [8], vegetation and growth substrates used in green roofs can contribute to the reduction of CO_2 directly, while the energy consumption of buildings can be reduced indirectly, by reducing the use of fossil fuels and, therefore, emissions of CO_2 globally. When plant species were mixed, this was proved to be more energy-efficient [83,84], while a varied seed/plant mix, sedums, annuals, and perennials are suggested for a more natural green roof, with excellent carbon sequestration habitats [28].

In the case that urban agriculture is pursued, the purpose to maximize herb crop yield should also be succeeded. At the end of the first period, when both species collected were being flowered, fresh and dry weights of all plant parts were greater in *C. maritimum* compared to *O. dictamnus*, as well as in the deep substrates compared to the shallow ones, especially in the case of *C. maritimum*. During the second period, plants of *C. maritimum* and *O. dictamnus* were collected in June and August, respectively, when their edible parts are practically collected to be used as herbs. In *C. maritimum*, fresh and dry weights of foliage were greater in the deep substrates, while, in *O. dictamnus*, fresh and dry weights of foliage and flowers were greater in the deep substrate with soil. Thus, the increased substrate depth positively affected the quantity of crop yield produced, which is desirable in urban agriculture, and, in the case of *O. dictamnus*, adding soil to the substrate could also be considered.

During both cultivation periods, a seasonality in plant growth was observed. After planting at the end of December 2015, there was a stability in plants' growth until March, followed by a period of rapid growth during April to August. Especially after June, when the formation of inflorescences started for both species, a significant increase in their dimensions in height and diameter was observed. Then, their growth remained stable during the September to February period and started increasing again in the following spring and summer, due to favorable climatic conditions (higher temperature and solar radiation) and the longer photoperiod. Growth during the second cultivation period was lower because of the heat stress experienced by the plants in June 2017.

The plants studied also showed a different adaptive mechanism to heat stress, since *C. maritimum* showed severe dehydration of its succulent leaves, while *O. dictamnus* showed drying in parts of the plant and some defoliation, the latter presenting the typical response of Mediterranean xerophytes to drought. The dehydration process leads to the reduction in leaf surface that is the avoidance mechanism [85] leading to water loss reduction. Under drought conditions, the above-ground biomass in many plant species decreases more than the root biomass, resulting in a higher root/above-ground ratio [14,86], thereby optimizing water uptake [87].

5. Conclusions

Both *Crithmum maritimum* and *Origanum dictamnus* grew well on an extensive urban Mediterranean green roof in all the tested substrate types and depths, and the following differences were observed in their growth:

O. dictamnus showed smaller growth than *C. maritimum* during the first growth period, but, during the second growth period, its growth surpassed that of *C. maritimum,* indicating the slower growth rate of *O. dictamnus* during establishment and first growth.

In both species, the deep substrate favored all the growth parameters studied, i.e., plant height, foliage diameter, the plant canopy growth index, fresh and dry weights of flowers, foliage and roots, although they were satisfactory in the shallow one as well. Also, deep substrates produced the maximum amount of herbal crop yield, regardless of the substrate type for *C. maritimum*, while it was favored by the addition of soil in *O. dictamnus*.

Regarding substrate type, *O. dictamnus* responded better in the substrate that contained soil regarding survival, growth, and flowering, as opposed to *C. maritimum* that showed equal response in both substrate types.

The fact that the plants suffered temperature stress, because of a heat wave, close to the end of the experiment, showed that the bigger depth of the substrate made plants of both species more resistant, as well as the substrate with soil in case of *O. dictamnus*.

Although a soilless substrate vs. a soil-containing type or a shallow substrate vs. a deep one should be preferred in cases of green roof cultivation, in order to reduce the construction weight, when plants grow satisfactorily in both cases, in the era of climate change, maybe, the choice that makes plants more resistant to adverse environmental conditions should also be considered.

Both *Crithmum maritimum* and *Origanum dictamnus* are recommended for use in sustainable green roofs and urban horticulture, preferring the soilless lightweight substrate for the first species and the one with soil for the second one. Although deep substrate favors all growth parameters and plant survival, the choice of substrate depth should depend on the properties and strength of the building. The contribution of plants to the reduction of CO_2 from the urban environment should also be considered, especially of *C. maritimum*, due to the greater biomass it produced under the same crop inputs.

The establishment of green roofs in cities with limited green areas, even in semiarid/arid regions, is indicated as a way of dealing with the climate crisis, the strengthening of biodiversity, the practice of urban agriculture, and the aesthetic improvement of cities. Plant species, such as native ones, adapted to the environmental conditions of the area, must continue to be investigated, in terms of their resistance to cultivation in the adverse conditions of an extensive-type green roof and to limited irrigation in semiarid/arid regions. Particular emphasis should be placed on the contribution of plant species to the removal of CO_2 from the atmosphere, the provision of habitat for local fauna, as well as their contribution to the development of urban agriculture with reduced input needs, as research data in these areas are limited. Also, locally produced substrates should continue to be explored for their potential utilization in green roofs, with the aim of contributing to reductions in carbon footprint.

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