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Assessing the Performance of *Jacobaea maritima* subsp. *sicula* on Extensive Green Roofs Using Seawater as an Alternative Irrigation Source

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Abstract

Freshwater scarcity and saline groundwater are major constraints for maintaining green roofs in coastal areas. This study evaluated the response of *Jacobaea maritima* subsp. *sicula*, (Sicilian silver ragwort) a drought-tolerant coastal ornamental plant, to tap water and seawater irrigation under Mediterranean summer conditions. Plants were grown in 10 cm-deep green-roof modules and subjected to six irrigation regimes: tap water, seawater, or alternating tap water and seawater, each applied at 4- or 8-day intervals, with irrigation volumes equal to 60% of cumulative reference evapotranspiration (ET_o). Growth, relative water content (RWC), chlorophyll index (SPAD), and leachate electrical conductivity were monitored to assess plant performance and salinity responses. Seawater irrigation caused rapid substrate salinization, leaf dehydration, and plant death within one month, while alternating seawater with tap water also failed to sustain survival. In contrast, tap water–irrigated plants maintained high RWC, chlorophyll content, and stable visual quality throughout the experimental period, even with deficit irrigation at 60% ET_o every eight days. These findings demonstrate that *J. maritima* subsp. *sicula* is well suited for freshwater-irrigated extensive green roofs in semi-arid regions, providing reliable performance under infrequent irrigation and limited water supply. However, seawater or high-salinity irrigation should be avoided. Future research should explore mixed freshwater–seawater irrigation regimes with a higher freshwater proportion, aiming to reduce total freshwater consumption while sustaining plant survival and esthetic performance.

Keywords: drought-tolerant ornamentals; leachate salinity; Mediterranean climate; relative water content; salinity stress; Sicilian silver ragwort; SPAD index

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1. Introduction

Urbanization and climate change are imposing increasing pressure on cities, particularly in coastal Mediterranean regions characterized by semi-arid conditions [1]. The continuous expansion of impervious surfaces reduces natural stormwater infiltration, exacerbates urban overheating and intensifies environmental stress on both residents and urban biodiversity [2]. Among nature-based solutions, green roofs are widely recognized as sustainable technologies that mitigate urban heat stress, improve stormwater management, enhance urban biodiversity, and contribute to esthetic quality [3]. However, the broader implementation of green roofs is often constrained by the load-bearing capacity of existing buildings, especially in older urban areas [4]. For this reason, extensive green roofs, characterized by shallow substrates not exceeding 15 cm and low maintenance requirements, are the most adopted systems in Mediterranean cities [5,6].

At the same time, rising air temperatures, irregular rainfall, and freshwater scarcity in semi-arid regions make it increasingly difficult to establish and maintain urban green spaces, particularly extensive green roofs [7,8]. Suitable species must tolerate restricted rooting depth, extreme fluctuations in substrate temperature, and prolonged periods of limited irrigation [9,10]. Consequently, succulents and other xerophytic species are commonly used, restricting plant diversity and limiting both the ornamental and ecological potential of these systems [11,12]. Expanding the palette of suitable plants requires exploring irrigation practices that can sustain less drought-tolerant yet esthetically valuable species, hence improving green roof biodiversity and functionality.

Freshwater scarcity in coastal Mediterranean regions has intensified interest in the use of alternative water sources, including saline or recycled water, for landscape irrigation [13]. While seawater is abundant, its high salinity imposes osmotic and ionic stresses as well as nutrient imbalances that restrict its direct use for most ornamentals [14,15]. In natural urban green spaces, repeated application of seawater irrigation can also lead to excessive salt accumulation in soil, further compromising plant growth and survival [16]. By contrast, green roof substrates, typically composed of coarse-textured, highly porous materials, facilitate rapid drainage and effective leaching of salts [17]. In addition, the engineered drainage layer allows controlled collection of leachates, thereby reducing the risk of groundwater contamination or soil salinization. These features make extensive green roofs particularly suitable experimental systems for testing saline irrigation strategies and for identifying ornamental species that can tolerate seawater, whether applied directly, diluted, or alternated with tap water.

Previous studies have explored seawater irrigation on green roofs, highlighting both its potential and limitations. Paraskevopoulou et al. [18] investigated the halophyte *Arthrocnemum macrostachyum* (Moric.) K. Koch in extensive green roofs and found that both partial and exclusive seawater irrigation were feasible when applied at high frequencies (every 4 days), highlighting the species' suitability for green roof systems irrigated with seawater. Ntoulas and Varsamos [19] evaluated two seashore paspalum (*Paspalum vaginatum* Sw.) varieties ('Marina' and 'Platinum TE') grown in extensive green roofs and reported that exclusive seawater irrigation severely reduced turf quality. However, they also found that applying seawater at higher irrigation volumes increased the leaching fraction and maintained leachate electrical conductivity closer to that of the applied seawater, consequently reducing salt accumulation in the substrate and partially alleviating salinity stress, which in turn supported turfgrass survival. In a follow-up study, Ntoulas et al. [20] reported that alternating seawater with potable water (1:1) could sustain acceptable growth, but only for limited periods. These findings highlight the importance of irrigation frequency, volume, and leaching management when considering seawater as an alternative resource for green roof irrigation.

Jacobaea maritima (L.) Pelser & Meijden, syn. *Cineraria maritima* (L.) L. and *Senecio cineraria* DC., commonly known as Silver ragwort, is a perennial ornamental species, valued for its distinctive silver-gray, tomentose foliage [21] and notable drought tolerance [22,23]. It produces bright yellow, daisy-like flower heads from early to late summer, adding seasonal ornamental interest; however, it is more appreciated for the decorative features of its foliage than for its flowers [24]. The species is native to the Mediterranean region [25] and is widely used in urban plantings [26], improving air quality [27]. Its adaptability to limited irrigation suggests potential suitability for extensive green roof systems [28], yet its response to saline irrigation under shallow substrate conditions remains unknown. In the present study, the plant material corresponded to *Jacobaea maritima* subsp. *sicula* (Sicilian silver ragwort), a coastal taxon native to the Central Mediterranean and found on maritime cliffs and rocky coastal slopes [29].

This study assessed the growth and physiological responses of *J. maritima* subsp. *sicula* to tap water, seawater, and alternating tap water–seawater irrigation under simulated extensive green roof conditions during the Mediterranean summer. To our knowledge, this is the first study to investigate the performance of *J. maritima* subsp. *sicula* under seawater irrigation, addressing the dual challenges of freshwater conservation and plant selection for sustainable and resilient green roofs.

2. Materials and Methods

2.1. Experimental Setup

The study was conducted outdoors at the experimental field of the Laboratory of Floriculture and Landscape Architecture, Agricultural University of Athens, Greece (37°59′ N, 23°42′ E). (Figure 1). Thirty rectangular plastic containers (Holiday Land S.A., Piraeus, Greece) with internal top dimension of 49 × 34 cm and a height of 16 cm were placed on metal benches at ~1% slope to facilitate drainage. A 15 mm drainage hole was opened near the lower end of each container and connected via flexible tubing to a sealed 5 L tank positioned beneath to collect leachates (Figure 2).

Figure 1. Experimental setup of the simulated extensive green roof modules with *Jacobaea maritima* subsp. *sicula* plants at the experimental field of the Laboratory of Floriculture and Landscape Architecture, Agricultural University of Athens.

Each container was filled with a layered extensive green roof system (Figure 2). A protection and water retention mat (VLS-500, DIADEM, Landco Ltd., Athens, Greece) was placed at the bottom of the containers, which was a synthetic sheet made of non-rotting synthetic fibers, having a 4 mm thickness and was able to retain 3.6 L m^{-2} of water. On top, a 25 mm drainage board (DiaDrain-25H, DIADEM, Landco Ltd.) was placed. The drainage layer, which was made of recycled high-impact polystyrene, was equipped with water retaining troughs, having a water holding capacity of 11.8 L m^{-2} and openings to enhance sub-surface aeration. The drainage layer was covered with a non-woven geotextile (VLF-150, DIADEM, Landco Ltd.) of reinforced polypropylene, having a thickness of

1.2 mm and a water permeability of 105 mm s^{-1}, to prevent fine substrate particles from clogging the drainage layer. Finally, a 10 cm layer of FLL-compliant lightweight extensive green roof substrate (SEM, Prasini Stegi, Landco Ltd., Athens, Greece) (Table 1) was added, gently leveled, and lightly compacted.

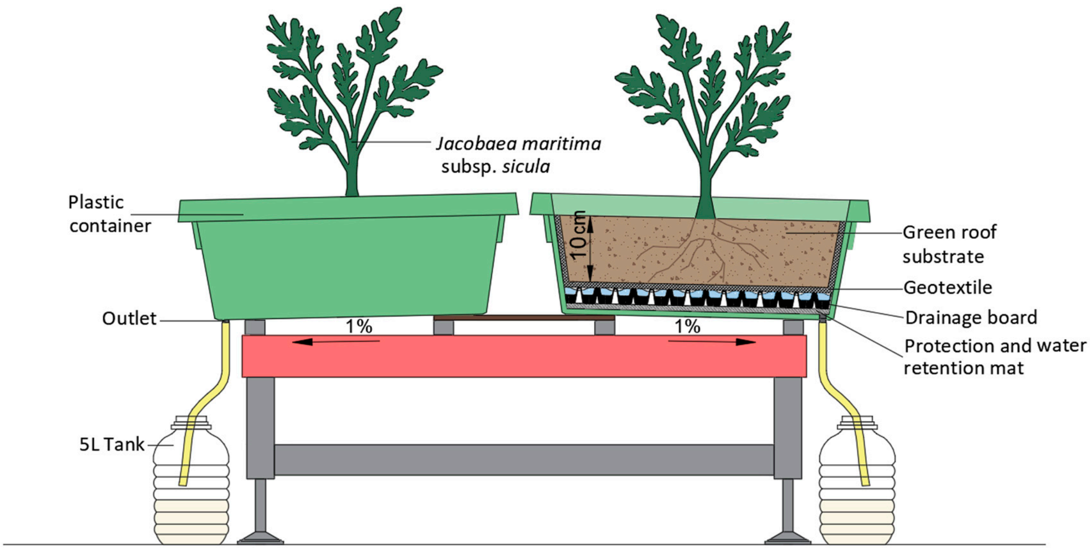

Figure 2. Construction detail of the simulated extensive green roof modules used in the study.

Table 1. Physical and chemical properties of the substrate used in the study (SEM, Prasini Stegi, Landco Ltd., Athens, Greece).

Parameter	Value	Mechanical Analysis	
		Particle Size	Percent Retained
		mm	% (*w*/*w*)
pH ($CaCl_2$)	7.3	>12.5 mm	0.3
Electrical conductivity (water, 1:10, m:v), dS m^{-1}	0.19	12.5–9.5 mm	5.9
Dry bulk density, kg L^{-1}	0.98	9.5–6.3 mm	8.4
Bulk density at maximum water-holding capacity, kg L^{-1}	1.36	6.3–3.2 mm	18.7
Total pore volume, %	56.7	3.2–2.0 mm	24.7
Maximum water-holding capacity, % (*v*/*v*)	40.7	2.0–1.0 mm	19.5
Air-filled porosity, % (*v*/*v*)	16.0	1.0–0.25 mm	12.1
Water permeability, cm·s^{-1}	0.007	0.25–0.05 mm	4.3
Organic matter content, % (*w*/*w*)	7.5	0.05–0.002 mm	4.7
Phosphorus, P_2O_5 (CAL), mg L^{-1}	167.4	<0.002 mm	1.2
Potassium, K_2O (CAL), mg L^{-1}	663.8		
Magnesium, Mg ($CaCl_2$), mg L^{-1}	165.7		
Nitrate + Ammonium ($CaCl_2$), mg L^{-1}	1.5		

Uniform plants of *J. maritima* subsp. *sicula* (identified following Passalacqua et al. [29]) were sourced from a local nursery and transplanted individually in the center of each container on 21 April 2021. Following transplanting, plants were irrigated with tap water every other day to promote establishment. Salinity treatments began 40 days after transplanting and continued for 97 days (30 June–4 October 2021). The experiment ended with the first autumn rainfall on 8 October 2021. During the trial, weather conditions were typical of a Mediterranean summer, suitable for testing seawater irrigation, as no rainfall occurred apart from a negligible shower of 0.2 mm on 9 September 2021 (Figure 3). Daily mean air temperature ranged from 18.6 °C (23 September) to 36.5 °C (3 August), with an average of

27.6 ± 3.8 °C, based on the records of the National Observatory of Athens (Thissio station; 37°58′ N, 23°43′ E).

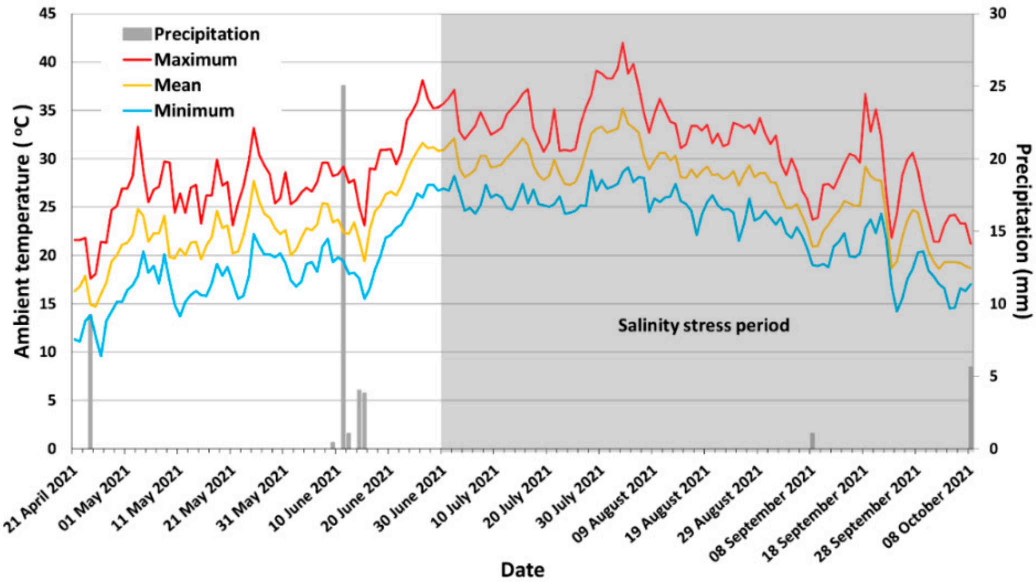

Figure 3. Daily maximum, mean, and minimum ambient air temperatures (°C) and precipitation (mm) recorded at the Thissio station of the National Observatory of Athens during the experimental period. (21 April–8 October 2025). The shaded area marks the salinity stress treatment period (30 June–8 October 2021).

2.2. Irrigation Regimes

At treatment initiation (30 June 2021), all plants were irrigated with tap water to saturate the substrate and ensure uniform moisture conditions. Thereafter, six irrigation regimes were studied: tap water, seawater, or alternating seawater and tap water, each applied at 4- or 8-day intervals. At each irrigation, the applied volume equaled 60% of the cumulative reference evapotranspiration (ET_o) that was calculated since the previous irrigation, with ET_o determined from an adjacent Class A pan using a pan coefficient of 0.65, following FAO Irrigation and Drainage Paper 56 [30] (Figure 4). The treatment with 60% ET_o was selected to simulate deficit irrigation, a common practice in extensive green roofs with drought-tolerant plants, to reduce water use while maintaining plant performance. Although lower replacement ratios could further maximize water savings, they often fail to secure any leaching. For this reason, a 60% threshold was chosen in the present study to achieve water conservation while ensuring at least minimal leaching. This is critical because leaching is the most important factor in mitigating salinity stress under saline irrigation [31–33].

The 4-day interval represented a frequent irrigation strategy aimed at maintaining favorable water status in the simulated green roofs. By contrast, the rationale for including the longer irrigation interval was twofold. First, the larger cumulative irrigation volume applied every 8 days was expected to produce a higher leaching fraction, thereby promoting salt leaching and helping to maintain substrate salinity at lower levels. Second, the 8-day regime provided an opportunity to assess the tolerance of *J. maritima* subsp. *sicula* to extended intervals without irrigation, which is highly relevant to green roof applications in semi-arid Mediterranean climates where irrigation frequency is often restricted.

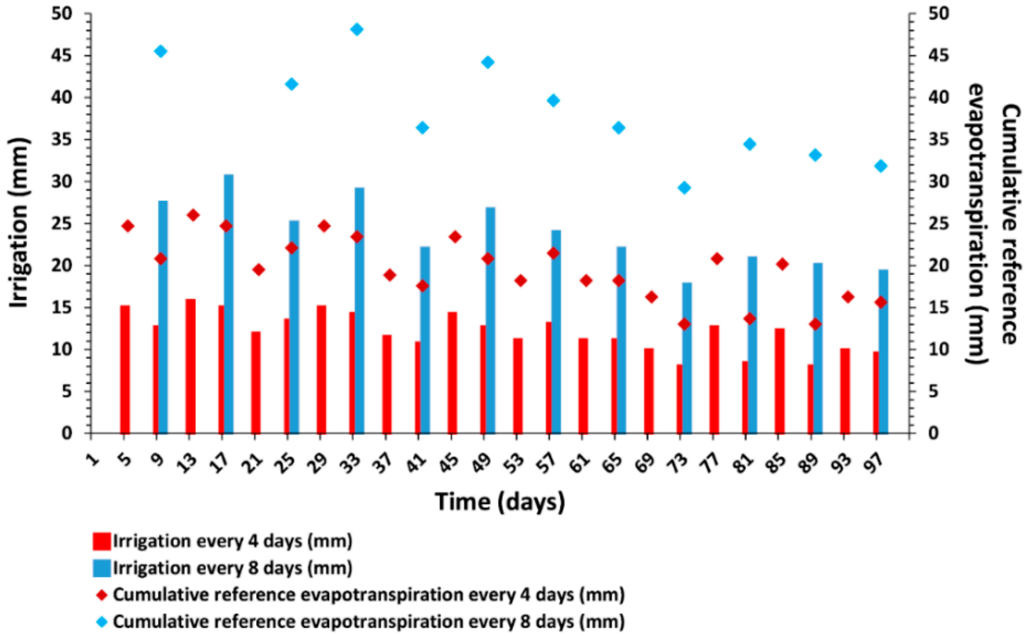

Figure 4. Irrigation volumes (mm) applied every 4 and 8 days (bars) and corresponding cumulative reference evapotranspiration (mm) (symbols) during the salinity stress period (30 June–8 October 2021).

Tap water had an electrical conductivity (EC, 25 °C) of 0.3 dS m^{-1}. Seawater was collected once from Drapetsona, Attica, Greece (37°57′ N, 23°37′ E), stored in a shaded plastic tank, and used throughout the experiment. Its EC at 25 °C was 57.6 dS m^{-1}, with the full chemical composition shown in Table 2. The salinity of the stored seawater was periodically checked and showed no significant variation during the study. Plants were hand-irrigated with a watering can fitted with a rose head to ensure uniform distribution across the substrate surface. To minimize variability from manual watering, the same person applied irrigation at a uniform flow rate across all replicates. No fertilization was applied during the trial.

Table 2. Chemical analysis of seawater used for extensive green roof modules irrigation during salinity stress period (30 June–8 October 2021).

Parameter	Value
pH	8.2
Electrical conductivity (25 °C), dS m^{-1}	57.6
Total hardness, mg $CaCO_3$ L^{-1}	6615
Carbonate (CO_3^{2-}), mg L^{-1}	32.4
Bicarbonate (HCO_3^{-}), mg L^{-1}	136
Sulfate (SO_4^{2-}), mg L^{-1}	2350
Chloride (Cl^{-}), mg L^{-1}	22,100
Calcium (Ca^{2+}), mg L^{-1}	415
Magnesium (Mg^{2+}), mg L^{-1}	1284
Potassium (K^{+}), mg L^{-1}	399
Sodium (Na^{+}), mg L^{-1}	10,900
Iron (Fe), µg L^{-1}	304

2.3. Measurements

After each irrigation, leachates collected in the tanks were measured for EC at 25 °C with a handheld conductivity meter (HI98192, Hanna Instruments Inc., Woonsocket, RI, USA), and the tanks were subsequently rinsed thoroughly with tap water to prevent salt accumulation. The leaching fraction (LF) was calculated as the ratio of leachate volume to irrigation volume. Plant size was recorded every 8 days using a growth index (GI) calculated as (height + largest canopy diameter + perpendicular diameter)/3 [34]. This metric integrates vertical and horizontal growth into a single parameter, allowing for a reliable assessment of plant size over time.

Leaf relative water content (RWC) was determined following Turner [35]. Every 8 days, immediately before irrigation (12:00–14:00 h), fully expanded leaves (0.5–1.0 g per plot) were sampled and weighed for fresh weight (FW). Samples were immersed in deionized water for 24 h, blotted, and weighed for turgid weight (TW). They were then oven-dried at 75 °C for 48 h and weighed for dry weight (DW). The RWC (%) was calculated as $100 \times (FW - DW)/(TW - DW)$. This parameter was used to evaluate plant water status and the degree of osmotic stress under the different irrigation regimes.

Leaf greenness (SPAD index) was also assessed every 8 days using a portable chlorophyll meter (SPAD-502, Spectrum Technologies Inc., Aurora, IL, USA). For each plant, six readings from different fully expanded leaves were averaged. This index served as an indirect measure of chlorophyll concentration and photosynthetic capacity, providing further insight into plant physiological performance under saline stress [15].

2.4. Experimental Design and Statistics

Treatments were arranged in a completely randomized design using the randomization function in Microsoft Excel (Microsoft Corp., Redmond, WA, USA), with five replicates per treatment, resulting in 30 experimental plots (i.e., six irrigation treatments × five replications = 30 experimental plots). Each plot consisted of a single plant grown in an individual container, ensuring independence among replicates.

Collected data for leachate electrical conductivity, growth index, relative water content, and SPAD index were subjected to one-way analysis of variance (ANOVA) within each sampling date using Statgraphics Centurion v15.2.11 statistical software (Statpoint Technologies Inc., Warrenton, VA, USA). Treatment means were separated using Fisher's protected least significant difference (LSD) at a 0.05 probability level ($p < 0.05$).

3. Results and Discussion

3.1. Leachate Electrical Conductivity

Leachate electrical conductivity (EC_L) closely reflected irrigation treatments and provided a direct indicator of salt accumulation in the 10 cm substrate [36]. In treatments irrigated exclusively with seawater, EC_L increased rapidly and exceeded the salinity of the applied seawater (57.6 dS m^{-1}) within 12–16 days, whereas this threshold was reached more gradually, within 20–24 days in irrigation treatments alternating seawater with tap water (Figure 5). Continued irrigation exclusively with seawater every 4 days led to further salt accumulation, with EC_L values doubling the seawater salinity by the end of the first month. This salinity increase can be attributed mainly to evaporative concentration and limited leaching as a result of deficit irrigation, rather than to restricted drainage, since the substrate used in this study exhibited high water permeability (Table 1). By contrast, seawater applied every 8 days maintained EC_L at significantly lower levels, although values still reached 86 dS m^{-1} after one month. This effect can be attributed to the larger cumulative irrigation volumes every 8 days, which produced higher leaching. In tap water treatments, EC_L remained consistently low (<3 dS m^{-1}) throughout the study period. Alternating irrigation with seawater and tap water resulted in fluctuating EC_L values near seawater salinity, as periodic tap water applications temporarily reduced the accumulated salts; however, this dilution effect was insufficient to counterbalance the high ionic load of seawater.

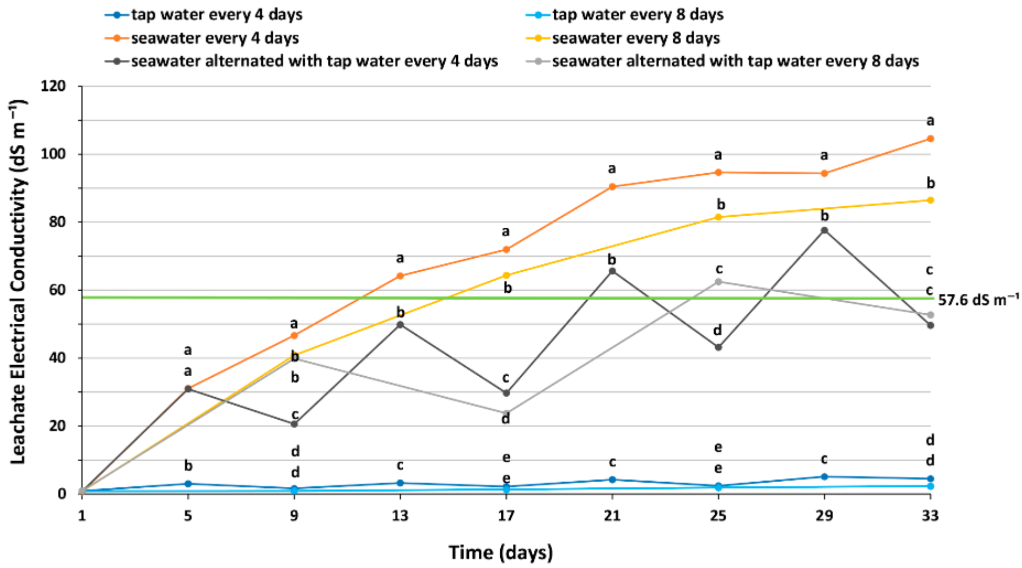

Figure 5. Leachate electrical conductivity (dS m^{-1}) as affected by irrigation treatments during the study period (30 June, day 1–4 October, day 97). The electrical conductivity of the applied seawater (57.6 dS m^{-1}) is shown. Values are means of five replicates. Different letters on a given day indicate significant differences between treatments at $p < 0.05$ using Fisher's least significant difference (LSD).

Similar findings were reported by Paraskevopoulou et al. [18], who evaluated the halophyte *Arthrocnemum macrostachyum* in extensive green roofs irrigated with partial or exclusive seawater. They observed that seawater irrigation at 4-day intervals rapidly increased EC_L above the salinity of the applied seawater, while alternating seawater with tap water only delayed this increase but did not prevent salt accumulation. When seawater was applied at longer, 8-day intervals, EC_L values still increased but tended to remain significantly lower compared to the 4-day regime, as a result of the greater total irrigation volume applied at each event, which enhanced leaching efficiency under the less frequent but deeper irrigations. Ntoulas and Varsamos [19] showed that when seashore paspalum was irrigated exclusively with seawater on shallow green roof systems, low irrigation volumes resulted in small leaching fractions (0.4–0.5) causing EC_L to rise above the salinity of the applied seawater. In contrast, only excessive irrigation producing leaching fractions close to 0.9 was able to maintain EC_L at levels equivalent to the irrigation source.

In the present study, the average LF values during the first month were as follows: 0.19 for seawater every 4 days, 0.32 for seawater every 8 days, 0.14 for seawater alternated with tap water every 4 days, and 0.30 for seawater alternated with tap water every 8 days. These values confirm that irrigation volumes equivalent to 60% of ET_o, either every 4 days or 8 days, were insufficient to provide adequate leaching and prevent salt accumulation. Overall, the findings indicate that seawater use in extensive green roof systems demands substantially higher irrigation volumes or a much greater proportion of tap water in alternating regimes to secure adequate leaching. In practice, leaching requirements under seawater irrigation are extremely high if EC_L is to remain comparable to the salinity of the applied seawater. Otherwise, salts accumulate rapidly in the shallow substrate, driving EC_L to excessive levels. These results confirm that while green roof substrates facilitate drainage, maintaining effective leaching fractions is critical when irrigating with saline water [16,17].

3.2. Plant Growth Index

Growth of *J. maritima subsp. sicula*, expressed as growth index (GI), was vigorous in both tap water treatments (every 4 and 8 days), with no significant differences between irrigation frequencies throughout the 97-day study period (Figure 6). By the end of the study, plants irrigated with tap water every 4 days reached an average GI of 40.7 cm, while those irrigated every 8 days attained 38.7 cm. This demonstrates the species' tolerance to limited water supply and low irrigation requirements, consistent with its known drought tolerance [22,24], and highlights its potential for use in extensive green roofs requiring minimal water input under semi-arid Mediterranean conditions. Similarly, Guo et al. [28] evaluated 11 Mediterranean species on unirrigated green roofs under extremely hot and dry conditions and reported that *J. maritima* was among the best surviving species in both 10- and 15 cm substrate depths.

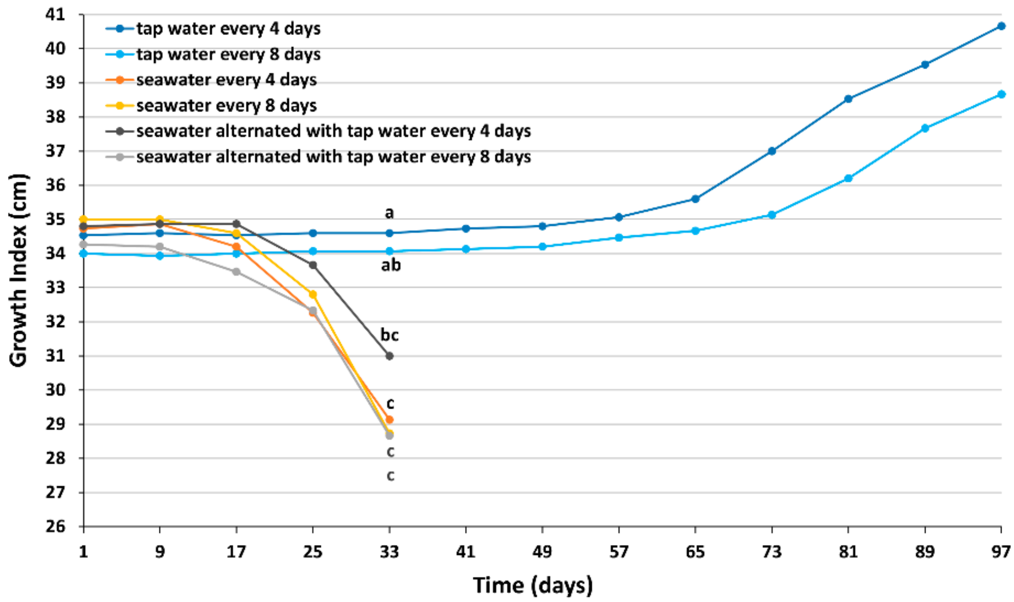

Figure 6. Growth index (cm) of *Jacobaea maritima* subsp. *sicula* as affected by irrigation treatments during the study period (30 June, day 1–4 October, day 97). Values are means of five replicates. Different letters on a given day indicate significant differences between treatments at $p < 0.05$ using Fisher's least significant difference (LSD).

In contrast, plants irrigated with seawater, either exclusively or alternating with tap water, exhibited a sharp decline in growth after 16–24 days (Figure 6). All seawater-irrigated plants died between 33 and 40 days after initiation of the study, indicating that Sicilian silver ragwort exhibits limited tolerance to full-strength seawater irrigation under green-roof conditions. Following plant death, no further physiological measurements were recorded for these treatments, as the last measurement was conducted on day 33.

Although *J. maritima* is often listed in horticultural sources as a salt-tolerant ornamental suitable for coastal or seaside plantings, its tolerance to saline irrigation has been only limitedly evaluated under experimental conditions. Observations from coastal Florida landscapes have noted that the species tolerates seawater spray [37]. Wang et al. [15], in a comprehensive review of ornamental plant responses to salinity, classified *J. maritima* among moderately salt-tolerant species and placed its irrigation salinity threshold near 13 dS·m^{-1} over a 30-day exposure period, values that correspond to roughly a quarter of seawater salinity. The present findings further indicate that, although *J. maritima* subsp. *sicula* is regarded as a salt-tolerant coastal ornamental, its performance declines markedly under the combined effects of undiluted seawater salinity, high summer temperatures, and the limited leaching typical of extensive green-roof systems. These results therefore represent an extreme salinity scenario. Future research should include intermediate salinity treatments to identify the transition from tolerance to intolerance and to develop practical irrigation guidelines for brackish or saline water use in green-roof applications.

Alternating seawater with tap water every 4 days delayed the decline slightly (Figure 6). By contrast, the more rapid decline observed under the 8-day alternating treatments can be attributed to the combined stress of extended irrigation intervals and cumulative salt accumulation, as indicated by the EC_L data (Figure 5). This phenomenon has been documented in other species as well, where limited water availability and salinity stresses interact synergistically [38]. Mndi et al. [39] reported that when *Mesembryanthemum crystallinum* was subjected to both salinity and longer irrigation intervals, the combined stresses exacerbated negative physiological effects more than each stress individually.

3.3. Leaf Relative Water Content

Leaf relative water content (RWC) is a widely accepted indicator of plant water status, reflecting the ability of leaf tissues to maintain hydration under conditions of water deficit or salinity stress [40,41]. Decline in RWC under saline conditions have been widely reported among ornamental species, including chrysanthemum (*Chrysanthemum* × *grandiflorum*), polygala (*Polygala myrtifolia*), and lavender (*Lavandula angustifolia*), all of which exhibit reductions in leaf water status when subjected to saline irrigation [42–44]. In the present study, RWC of *J. maritima* subsp. *sicula* varied significantly among irrigation treatments as salinity stress developed during the experimental period (Figure 7).

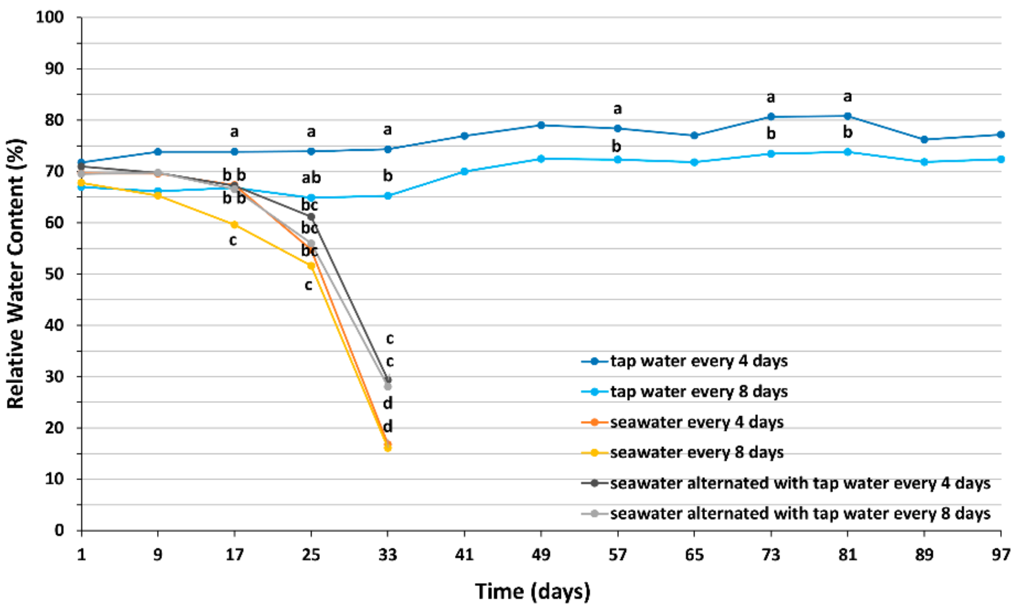

Figure 7. Leaf relative water content (%) of *Jacobaea maritima* subsp. *sicula* as affected by irrigation treatments during the study period (30 June, day 1–4 October, day 97). Values are means of five replicates. Different letters on a given day indicate significant differences between treatments at $p < 0.05$ using Fisher's least significant difference (LSD).

In the tap water treatments, plants maintained consistently high RWC values (>70%) throughout the 97-day trial (Figure 7). Plants irrigated every 4 days exhibited significantly higher RWC on several sampling dates compared with those irrigated every 8 days; however, both regimes ensured adequate hydration to sustain vigorous growth (Figure 7). This stability in leaf water status demonstrates the species' capacity to maintain tissue hydration under reduced irrigation frequency.

By contrast, exclusive seawater irrigation caused a rapid and severe decline in RWC (Figure 6). Values dropped sharply from day 17 onward, falling below 55% by day 25 and reaching levels below 20% by day 33, coinciding with visible leaf wilting and plant death. Under the 8-day seawater irrigation, RWC decreased even faster than under the 4-day regime, reflecting the synergistic impact of prolonged irrigation intervals and cumulative salt accumulation.

Plants subjected to alternating seawater and tap water irrigation exhibited a slower decline in RWC, maintaining values above 55% until day 25 (Figure 7). Thereafter, RWC decreased rapidly, yet remained significantly higher than in exclusive seawater treatments by day 33, though still below 30%. The sharp decline in RWC closely mirrored the reduction in the corresponding growth index observed under saline irrigation (Figure 6), indicating that the loss of cellular turgor was a primary cause of growth cessation and mortality in *J. maritima* subsp. *sicula*.

These results highlight the species' inability to maintain water balance under high salinity. Osmotic stress induced by elevated substrate EC, combined with ionic toxicity, likely restricted water uptake and accelerated dehydration, while fluctuations in substrate temperature during the summer period may have further intensified these effects by enhancing evapotranspiration and ion accumulation in seawater-irrigated plants [45,46]. In contrast, *A. macrostachyum*, as a halophytic species when evaluated under comparable conditions by Paraskevopoulou et al. [18], maintained RWC values above 75% throughout a three-month seawater irrigation period due to efficient osmotic adjustment. Although Saito et al. [47] reported that *J. maritima* can exclude Na^+ ions from its shoots and maintain salt tolerance under 100–200 mM NaCl, these adaptive mechanisms may be insufficient to offset the much greater osmotic potential and ionic toxicity associated with seawater salinity (≈600 mM NaCl). Consequently, the plants experienced rapid dehydration and eventual mortality. This suggests that while *J. maritima* subsp. *sicula* may exhibit tolerance at low to moderate salinity levels, its defense mechanisms become overwhelmed under the extreme ionic loads imposed by seawater irrigation.

3.4. SPAD Index

Salinity stress strongly affected the leaf greenness of *J. maritima*, subsp. *sicula* as indicated by changes in SPAD values (Figure 8). In the tap water treatments, plants maintained high chlorophyll levels throughout the 97-day experimental period, with no significant differences between the two irrigation intervals. A temporary decline observed in mid-August was likely associated with peak summer temperatures recorded earlier this month (Figure 3). As temperatures decreased, stress symptoms subsided, and chlorophyll levels recovered. Overall, the maintenance of high SPAD readings confirms the species' ability to preserve photosynthetic efficiency under limited irrigation.

In contrast, plants subjected to seawater irrigation exhibited a sharp and irreversible decline in SPAD values immediately after treatment initiation (Figure 8). Even after the first irrigation event, SPAD readings decreased noticeably, as according to the EC_L data (Figure 5) a single seawater application raised the substrate salinity to levels that likely far exceeded the salinity tolerance threshold of *J. maritima* subsp. *sicula*. This response suggests that Sicilian silver ragwort has a substantially lower threshold for irrigation water salinity than that of seawater. Continued application of seawater further increased substrate salinity, intensifying osmotic and ionic stress on the plants. Under both exclusive seawater irrigation and alternating seawater with tap water, SPAD values fell below 30 within 25 days, representing a 30–40% reduction, and dropped below 20 by day 33 (approximately 48–54% reduction), coinciding with visible symptoms of chlorosis and necrosis. These findings indicate that periodic tap water applications were insufficient to prevent chlorophyll degradation or to mitigate the cumulative effects of salinity stress. Comparable rapid declines in SPAD values have been observed in other ornamental species when irrigation water salinity exceeded their tolerance limits [15,48,49].

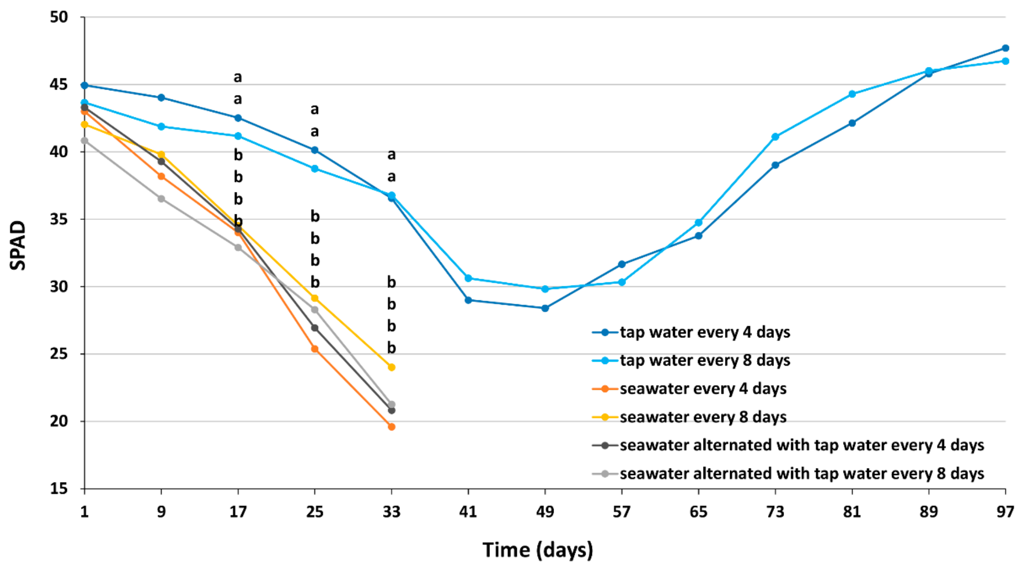

Figure 8. Leaf greenness (SPAD index) of *Jacobaea maritima* subsp. *sicula* as affected by irrigation treatments during the study period (30 June, day 1–4 October, day 97). Values are means of five replicates. Different letters on a given day indicate significant differences between treatments at $p < 0.05$ using Fisher's least significant difference (LSD).

4. Conclusions

The present study provides the first systematic evaluation of *Jacobaea maritima* subsp. *sicula* performance under saline irrigation in extensive green roof systems. The results indicate that the subspecies can maintain vigorous growth and high esthetic quality under limited irrigation but exhibits pronounced sensitivity to seawater salinity. Both exclusive or alternating seawater irrigation rapidly increased substrate EC beyond the species' tolerance threshold, resulting in reduced growth, sharp decline in relative water content and chlorophyll levels, and ultimately plant death within one month.

From a practical standpoint, *J. maritima* subsp. *sicula* is well suited for extensive green roofs in semi-arid Mediterranean regions, where it can maintain ornamental quality and physiological performance throughout the summer, even when irrigated every eight days at 60% of ET_o replacement. This highlights its potential for low-maintenance, water-efficient green roof systems. However, irrigation with seawater or other high-salinity sources should be avoided.

Future research should focus on identifying halophytic ornamentals capable of maintaining their esthetic and physiological performance under high salinity, as well as developing irrigation strategies that combine seawater and freshwater in mixed ratios (e.g., 1:2, 1:3, or higher). Such approaches could reduce overall freshwater use, mitigate substrate salt accumulation, and help define the salinity thresholds under which ornamental species can be sustainably cultivated in coastal urban green-roof systems.

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Abbreviations

The following abbreviations are used in this manuscript:

EC	Electrical Conductivity
EC_L	Leachate Electrical Conductivity
GI	Growth index
RWC	Leaf Relative Water Content
ET_o	Reference Evapotranspiration
FW	Fresh Weight
TW	Turgid Weight
DW	Dry Weight
SPAD	Soil–Plant Analysis Development
ANOVA	One-way Analysis of Variance
LSD	Least Significant Difference

References

1. Nastos, P.; Saaroni, H. Living in Mediterranean cities in the context of climate change: A review. *Int. J. Climatol.* **2024**, *44*, 3169–3190. [CrossRef]
2. Hobbie, S.E.; Grimm, N.B. Nature-based approaches to managing climate change impacts in cities. *Philos. Trans. R. Soc. B* **2020**, *375*, 20190124. [CrossRef]
3. Shafique, M.; Kim, R.; Rafiq, M. Green roof benefits, opportunities and challenges: A review. *Renew. Sustain. Energy Rev.* **2018**, *90*, 757–773. [CrossRef]
4. Ntoulas, N.; Nektarios, P.A.; Charalambous, E.; Psaroulis, A. *Zoysia matrella* cover rate and drought tolerance in adaptive extensive green roof systems. *Urban For. Urban Green.* **2013**, *12*, 522–531. [CrossRef]
5. Nektarios, P.A.; Kokkinou, I.; Ntoulas, N. The effects of substrate depth and irrigation regime on seeded *Sedum* species grown on urban extensive green roof systems under semi-arid Mediterranean climatic conditions. *J. Environ. Manag.* **2021**, *279*, 111607. [CrossRef]
6. Varela-Stasinopoulou, D.S.; Nektarios, P.A.; Ntoulas, N.; Trigas, P.; Roukounakis, G.I. Sustainable growth of medicinal and aromatic Mediterranean plants growing as communities in shallow substrate urban green roof systems. *Sustainability* **2023**, *15*, 5940. [CrossRef]
7. Okour, Y.; Shaweesh, H. Identifying the barriers to green infrastructure implementation in semi-arid urban areas using the DPSIR framework: A case study of Amman, Jordan. *City Environ. Interact.* **2024**, *24*, 100165. [CrossRef]
8. Vanuytrecht, E.; Van Mechelen, C.; Van Meerbeek, K.; Willems, P.; Hermy, M.; Raes, D. Runoff and vegetation stress of green roofs under different climate change scenarios. *Landsc. Urban Plan.* **2014**, *122*, 68–77. [CrossRef]
9. Kokkinou, I.; Ntoulas, N.; Nektarios, P.A.; Varela, D. Response of native aromatic and medicinal plant species to water stress on adaptive green roof systems. *HortScience* **2016**, *51*, 608–614. [CrossRef]
10. Papafotiou, M.; Martini, A.N.; Tassoula, L.; Stylias, E.G.; Kalantzis, A.; Dariotis, E. Acclimatization of Mediterranean native sages (*Salvia* spp.) and interspecific hybrids in an urban green roof under regular and reduced irrigation. *Sustainability* **2022**, *14*, 4978. [CrossRef]
11. Ndayambaje, P.; MacIvor, J.S.; Cadotte, M.W. Plant diversity on green roofs: A review of the ecological benefits, challenges, and best management practices. *Nat.-Based Solut.* **2024**, *6*, 100162. [CrossRef]
12. Todeschini, C.C.; Fett-Neto, A.G. Life at the top: Extensive green roof plant species and their traits for urban use. *Plants* **2025**, *14*, 735. [CrossRef] [PubMed]
13. Marcum, K.B. Use of saline and non-potable water in the turfgrass industry: Constraints and developments. *Agric. Water Manag.* **2006**, *80*, 132–146. [CrossRef]
14. Garcia-Caparros, P.; Lao, M.T. The effects of salt stress on ornamental plants and integrative cultivation practices. *Sci. Hortic.* **2018**, *240*, 430–439. [CrossRef]

15. Wang, Z.; Poudyal, S.; Kopp, K.; Zhang, Y. Response of ornamental plants to salinity: Impact on species-specific growth, visual quality, photosynthetic parameters, and ion uptake. *Front. Plant Sci.* **2025**, *16*, 1611767. [CrossRef]
16. Carrow, R.N.; Duncan, R.R.; Huck, M.T. *Turfgrass and Landscape Irrigation Water Quality: Assessment and Management*, 1st ed.; CRC Press: Boca Raton, FL, USA, 2009.
17. Ntoulas, N.; Papaioannou, G.; Bertsouklis, K.; Nektarios, P.A. Tolerance of tall fescue (*Festuca arundinacea* Schreb.) growing in extensive green roof systems to saline water irrigation with varying leaching fractions. *Land* **2024**, *13*, 167. [CrossRef]
18. Paraskevopoulou, A.T.; Ntoulas, N.; Bourtsoukli, D.; Bertsouklis, K. Effect of seawater irrigation on *Arthrocnemum macrostachyum* growing in extensive green roof systems under semi-arid Mediterranean climatic conditions. *Agronomy* **2023**, *13*, 1198. [CrossRef]
19. Ntoulas, N.; Varsamos, I. Performance of two seashore paspalum (*Paspalum vaginatum* Sw.) varieties growing in shallow green roof substrate depths and irrigated with seawater. *Agronomy* **2021**, *11*, 250. [CrossRef]
20. Ntoulas, N.; Kalampogias, C.; Nektarios, P.A. Alternate irrigation with seawater and potable water affects green coverage of two *Paspalum vaginatum* varieties grown on shallow green roof systems. *Rasen-Turf-Gazon—Eur. J. Turfgrass Sci.* **2020**, *51*, 32–33.
21. Cantor, M.; Grosu, E.F.; Buta, E.; Zaharia, A.; Jucan, D.; Sabo, R.A. Implementation of landscape design solutions with the color and texture of plants. *J. Hortic. For. Biotechnol.* **2018**, *22*, 22–28.
22. Pratesi, M.; Cinelli, F.; Santi, G.; Scartazza, A. Mediterranean green buildings: Vegetation cover and runoff water quality assessment in a green roof system. *Acta Hortic.* **2022**, *1345*, 235–242. [CrossRef]
23. Patti, M.; Musarella, C.M.; Spampinato, G. A habitat-template approach to green wall design in Mediterranean cities. *Buildings* **2025**, *15*, 2557. [CrossRef]
24. Cojocariu, M.; Chelariu, E.L.; Chiruță, C. Growth analysis of *Cineraria maritima* plants in green façade systems: Northeastern Romania climate study. *J. Appl. Life Sci. Environ.* **2023**, *56*, 25–39. [CrossRef]
25. Maggio, A.; Venditti, A.; Senatore, F.; Bruno, M.; Formisano, C. Chemical composition of the essential oil of *Jacobaea maritima* (L.) Pelser & Meijden and *J. maritima* subsp. *bicolor* (Willd.) B. Nord. & Greuter (Asteraceae). *Nat. Prod. Res.* **2014**, *29*, 857–863. [CrossRef]
26. Esfandiari, M.; Hakimzadeh Ardakani, M.A.; Sodaiezadeh, H. Investigation of heavy metal contamination in the ornamental plants of green spaces in the city of Yazd. *J. Ornam. Plants* **2020**, *10*, 213–222.
27. Hangan, A.M.R.; Cojocaru, A.; Teliban, G.C.; Amișculesei, P.; Stoleru, V. Preliminary study regarding the use of medicinal and decorative plants in the concept of peri-urban gardens with role on environmental protection. *Sci. Pap. Ser. B Hortic.* **2020**, *64*, 389–396.
28. Guo, B.; Arndt, S.; Miller, R.; Lu, N.; Farrell, C. Are succulence or trait combinations related to plant survival on hot and dry green roofs? *Urban For. Urban Green.* **2021**, *64*, 127248. [CrossRef]
29. Passalacqua, N.G.; Peruzzi, L.; Pellegrino, G. A biosystematic study of the *Jacobaea maritima* group (Asteraceae, Senecioneae) in the central Mediterranean area. *Taxon* **2008**, *57*, 893–906. [CrossRef]
30. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements*; FAO Irrigation and Drainage Paper 56; FAO: Rome, Italy, 1998.
31. Carrow, R.N.; Huck, M.T.; Duncan, R.R. Leaching for salinity management on turfgrass sites. *USGA Green Sect. Rec.* **2000**, *38*, 15–24.
32. Corwin, D.L.; Rhoades, J.D.; Šimůnek, J. Leaching requirement for soil salinity control: Steady-state versus transient models. *Agric. Water Manag.* **2007**, *90*, 165–180. [CrossRef]
33. Manzoor, M.Z.; Sarwar, G.; Aftab, M.; Tahir, M.A.; Zafar, A. Role of leaching fraction to mitigate adverse effects of saline water on soil properties. *J. Agric. Res.* **2019**, *57*, 275–280.
34. Nektarios, P.A.; Amountzias, I.; Kokkinou, I.; Ntoulas, N. Green roof substrate type and depth affect the growth of the native species *Dianthus fruticosus* under reduced irrigation regimens. *HortScience* **2011**, *46*, 1208–1216. [CrossRef]
35. Turner, N.C. Techniques and experimental approaches for the measurement of plant water status. *Plant Soil.* **1981**, *58*, 339–366. [CrossRef]
36. Kargas, G.; Ntoulas, N.; Tsapatsouli, A. Use of a dielectric sensor for salinity determination on an extensive green roof substrate. *Sensors* **2023**, *23*, 5802. [CrossRef] [PubMed]
37. Miyamoto, S. *Salt Tolerance of Landscape Plants Common to the Southwest*; Texas Water Resources Institute: El Paso, TX, USA, 2008. Available online: https://hdl.handle.net/1969.1/86110 (accessed on 6 October 2025).
38. Cao, H.; Ding, R.; Kang, S.; Du, T.; Tong, L.; Zhang, Y.; Chen, J.; Shukla, M.K. Drought, salt, and combined stresses in plants: Effects, tolerance mechanisms, and strategies. *Adv. Agron.* **2023**, *178*, 107–163. [CrossRef]
39. Mndi, O.; Sogoni, A.; Jimoh, M.O.; Wilmot, C.M.; Rautenbach, F.; Laubscher, C.P. Interactive effects of salinity stress and irrigation intervals on plant growth, nutritional value, and phytochemical content in *Mesembryanthemum crystallinum* L. *Agriculture* **2023**, *13*, 1026. [CrossRef]
40. Jones, H.G. Monitoring plant and soil water status: Established and novel methods revisited and their relevance to studies of drought tolerance. *J. Exp. Bot.* **2007**, *58*, 119–130. [CrossRef]

41. Meguekam, T.L.; Moualeu, D.P.; Taffouo, V.D.; Stützel, H. Changes in plant growth, leaf relative water content and physiological traits in response to salt stress in peanut (*Arachis hypogaea* L.) varieties. *Not. Bot. Horti Agrobot. Cluj-Napoca* **2021**, *49*, 12049. [CrossRef]
42. Bandurska, H.; Breś, W.; Tomczyk, A.; Zielezińska, M.; Borowiak, K. How chrysanthemum (*Chrysanthemum* × *grandiflorum*) 'Palisade White' deals with long-term salt stress. *AoB Plants* **2022**, *14*, plac015. [CrossRef]
43. Szekely-Varga, Z.; González-Orenga, S.; Cantor, M.; Jucan, D.; Boscaiu, M.; Vicente, O. Effects of drought and salinity on two commercial varieties of *Lavandula angustifolia* Mill. *Plants* **2020**, *9*, 637. [CrossRef]
44. Farieri, E.; Toscano, S.; Ferrante, A.; Romano, D. Identification of ornamental shrubs tolerant to saline aerosol for coastal urban and peri-urban greening. *Urban For. Urban Green.* **2016**, *18*, 9–18. [CrossRef]
45. Atta, K.; Mondal, S.; Gorai, S.; Singh, A.P.; Kumari, A.; Ghosh, T.; Roy, A.; Hembram, S.; Gaikwad, D.J.; Mondal, S.; et al. Impacts of salinity stress on crop plants: Improving salt tolerance through genetic and molecular dissection. *Front. Plant Sci.* **2023**, *14*, 1241736. [CrossRef]
46. Chen, H.; Jiang, J.G. Osmotic adjustment and plant adaptation to environmental changes related to drought and salinity. *Environ. Rev.* **2010**, *18*, 309–319. [CrossRef]
47. Saito, K.; Kuronuma, T.; Kanaya, T.; Watanabe, H. Assessment of ornamental plants using multiple salt tolerance indicators and classification of their physiological salt tolerance mechanisms. *J. Jpn. Soc. Reveget. Technol.* **2015**, *41*, 21–26. [CrossRef]
48. Liu, Q.; Sun, Y.; Niu, G.; Altland, J.; Chen, L.; Jiang, L. Morphological and physiological responses of ten ornamental taxa to saline water irrigation. *HortScience* **2017**, *52*, 1816–1822. [CrossRef]
49. Niu, G.; Rodriguez, D.S.; Aguiniga, L. Growth and landscape performance of ten herbaceous species in response to saline water irrigation. *J. Environ. Hortic.* **2007**, *25*, 204–210. [CrossRef]