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The Effect of Salinity on the Growth of Lavender Species

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Abstract: Long term degradation of water quality from natural resources has led to the use of alternative water resources for irrigation that are saline. Saline water irrigation in floriculture for the production of nursery crops requires an understanding of plant response. The pot growth of four lavender species (*Lavandula angustifolia*, *Lavandula dentata* var. *dentata*, *Lavandula dentata* var. *candicans* and *Lavandula stoechas*) irrigated with water containing different concentrations of NaCl (0, 25, 50, 100 and 200 mM) was investigated under greenhouse conditions. Overall results of different plant growth variables were consistent, showing a significant decrease at 100 and 200 mM NaCl. All lavender species showed signs of salinity stress that included chlorosis, followed by leaf and stem necrosis at NaCl concentrations greater than 50 mM. *L. dentata* var. *dentata* showed the greatest plant growth followed in descending order by *L. dentata* var. *candicans*, *L. stoechas* and *L. angustifolia*. Despite greater growth of *L. dentata* var. *dentata*, the appearance of *L. dentata* var. *candicans* was "healthier". In areas with saline irrigation water, *L. dentata* var. *dentata* and *L. dentata* var. *candicans* are proposed for the production of lavender nursery crops.

Keywords: floriculture; *Lavandula angustifolia*; *Lavandula dentata* var. *dentata*; *Lavandula dentata* var. *candicans*; *Lavandula stoechas*; saline water; irrigation; NaCl; chlorophyll fluorescence

1. Introduction

In arid, semi-arid and coastal areas, natural resources for good quality water have decreased. They are often characterized by high contents of total soluble salts due to groundwater overexploitation, seawater intrusion into aquifers and increased demand for freshwater, particularly in densely populated areas [1,2]. Long term degradation of water quality has led to the use of alternative water resources for irrigation derived from water reuse and recycling that is also saline [3,4]. Irrigation with saline water affects the growth and development of many plant species, even at low concentrations [5,6]. In the ground whether in the wild, field or garden, the effect of salinity on plants is determined by various variables such as ion concentration, soil composition, proximity to the sea, altitude, evapotranspiration rate, temperature and rainfall frequency [5–7]. In many parts of the world, salinity affects agricultural production and is predicted to become more intense in future decades [8]. It is considered as one of the most important stress factors in plant growth and yield that could lead to plant death under persisting

saline conditions [6,9]. Plant tolerance to salinity stress depends on the capacity of plants to exclude salt from the shoots or tolerate high leaf salt concentrations [10].

Irrigation with saline water initially creates a water deficit induced by osmotic stress and demonstrated by the reduced ability of plants to absorb water hence reduced plant growth rate [11]; the high saline concentrations cause osmotic and ionic imbalances between soil and plants, and plants exhibit signs of wilt despite the fact they have been irrigated [12,13]. Afterwards, a salt-specific or ion-excess effect of salinity is demonstrated by the salt entrance into the plant transpiration stream, causing eventual injury of transpiring leaf cells and further reduction of plant growth [11]. The high saline concentrations within the plant affect the anatomy, physiology and morphology of plant parts and particularly of leaves [4,6,14,15]. The salts absorbed by the plant are concentrated within the mature leaves, leading to leaf death over an extended time period due to the inability of leaf cells to compartmentalize salts in the vacuole; hence the salts either accumulate in the cytoplasm, inhibiting enzyme function, or accumulate in the cell walls, dehydrating the leaf cells [11]. The level of stress caused by salinity is dependent on the plant species and variety, the growth substrate and the applied method of irrigation. The more tolerant nonhalophytic species avoid the ion-excess effect. However, they may exhibit water deficits affecting cell extension and/or division. Therefore, potential reductions in photosynthesis may represent a secondary effect of reduced growth [16].

In floriculture, the use of saline water for the production of nursery crops requires an understanding of plant response to the effect of salinity through irrigation [17]. Some effects of salinity, on one hand, could be desirable such as decreased length and/or number of internodes [17] and others on the other hand could be undesirable such as chlorosis and marginal leaf necrosis. The effect of saline irrigation on floriculture has received less attention, as ornamental plants are normally irrigated with good-quality water [18,19]. In areas with limited or poor water quality resources, the cultivation of floriculture crops that can tolerate saline water irrigation can be an advantage [20]. Lavender species and varieties are popular floriculture crops. Lavender plants such as *Lavandula angustifolia*, *L. dentata*, and *L. stoechas* and their numerous cultivars are sold as ornamental plants for the garden. These species exhibit a variety of leaves and inflorescences with ornamental value and are highly aromatic due to the essential oils present in glands that cover much of the plant surface. The *Lavandula* genus includes 47 species and many varieties [21]. Some *Lavandula* species such as *Lavandula stoechas* and *Lavandula angustifolia* are found naturally growing in the Mediterranean coniferous coastal dune woodlands, coastal garrigues and sea cliffs, often exposed to sea spray [22,23]. The literature on the effect of saline irrigation on *Lavandula* species for nursery crops is limited. Potted *L. multifida* plants were able to grow in a mixture of sphagnum peat-moss and perlite when irrigated with 60 mM NaCl without significant biomass reduction [24]; however, the total plant dry weight of *L. multifida* decreased when irrigated with 100 mM and 200 mM NaCl [20,24]. Despite this, there are no comparative studies among different lavender species grown under greenhouse conditions and irrigated with different NaCl solutions.

This study examines the pot growth of four *Lavandula* species irrigated with different concentrations of saline water for nursery production to support floriculture in areas with poor water quality, using saline water for irrigation.

2. Materials and Methods

2.1. Experimental Site and Growth Conditions

Uniform in size, young (5 months old) and fully developed potted lavender plants were supplied by the nursery Kalantzis Plants (Marathonas, Greece). The pot size was 2.5 L (dimensions: 17 cm top diameter, 12.3 cm base diameter and 15 cm height). The growth substrate of the supplied potted lavender plants contained pure sphagnum peat (Base Substrate 2 medium, Klausmann-Deilmann Europe GmbH, Germany) and perlite (Perloflor, ISOCON S.A., Piraeus, Greece) in a 96:4 ratio (v/v) with pH 5.5–6.0 and EC 0.8 mS m^{-1}. Plants were placed on metal benches (dimensions: 2.5 m length, 0.85 m width and 0.80 m height) in an automated glass greenhouse of the Laboratory of Floriculture &

Landscape Architecture of the Agricultural University of Athens (lat. 37°58′57″N and long. 23°42′17″E), with average daily and night temperatures of 21.4 ± 0.311 °C and 14.3 ± 0.065 °C, respectively, and average humidity during daytime of 57.6 ± 0.705% and night-time average humidity of 84.6 ± 0.309%. Plants were acclimatized to the new growth conditions for a month and the experiment took place in late winter-early spring over 56 days (from 3 February; day 1 to 30 March 2018; day 56). All plants received the same cultivation practices (i.e., applications of fertilizer, fungicide, etc.) throughout the duration of the experiment that included the application of 2 g L^{-1} H_2O fertilizer 20-20-20 (Fast-Grow, Humofert S.A., Metamorfosi, Greece) and pesticide (Decis 25 EC, Bayer AG, Leverkusen, Germany) at monthly intervals.

2.2. Experimental Design and Irrigation Treatments

Four lavender species were studied: *Lavandula angustifolia*, *Lavandula dentata* var. *dentata*, *Lavandula dentata* var. *candicans* and *Lavandula stoechas*. The effect of salinity was investigated using different concentrations of NaCl solutions through irrigation that included 0 (control), 25, 50, 100 and 200 mM of NaCl. The corresponding EC levels for the irrigation water were 0.3, 3.0, 5.8, 10.6 and 20.7 dSm^{-1} and pH values were in the range 8.0–8.2 (at 25 °C).

Plants were arranged in a randomized complete block that consisted of 4 lavender species, 5 NaCl solution irrigation treatments and 6 replicates (plants) arranged in 3 blocks (metal benches) i.e., 2 plants per species and NaCl solution irrigation treatment per metal bench. The number of plants totaled 120 and the experimental surface area occupied approximately 6.5 m^2 (Figure 1).

At the start of the experiment (day 1), all plants were irrigated with the corresponding NaCl solutions to saturation and weighed half an hour later to determine the water container capacity of the substrate. Substrate water content was monitored using a handheld TDR moisture sensor (HH2, Delta-T Devise, Cambridge, UK) set at the 'organic soil' setting, appropriate for use with peat-based substrates and calibrated to the used substrate. The probes were fully inserted into the substrate with the central rod positioned 5 cm away from the plant center. Irrigation was performed manually when the TDR sensor showed a water content value of approximately 0.46 cm^3 cm^{-3}, which was determined from the substrate water retention curve at corresponding a pressure head of −50 cm (Figure 2), and with an amount of water ensuring substrate water availability within the easily available water area (Table 1). This amount of irrigation water of plants was determined with the mean accumulated daily difference in weight of six potted plants from each NaCl treatment between two consecutive irrigations that corresponded to the amount of water lost from evapotranspiration.

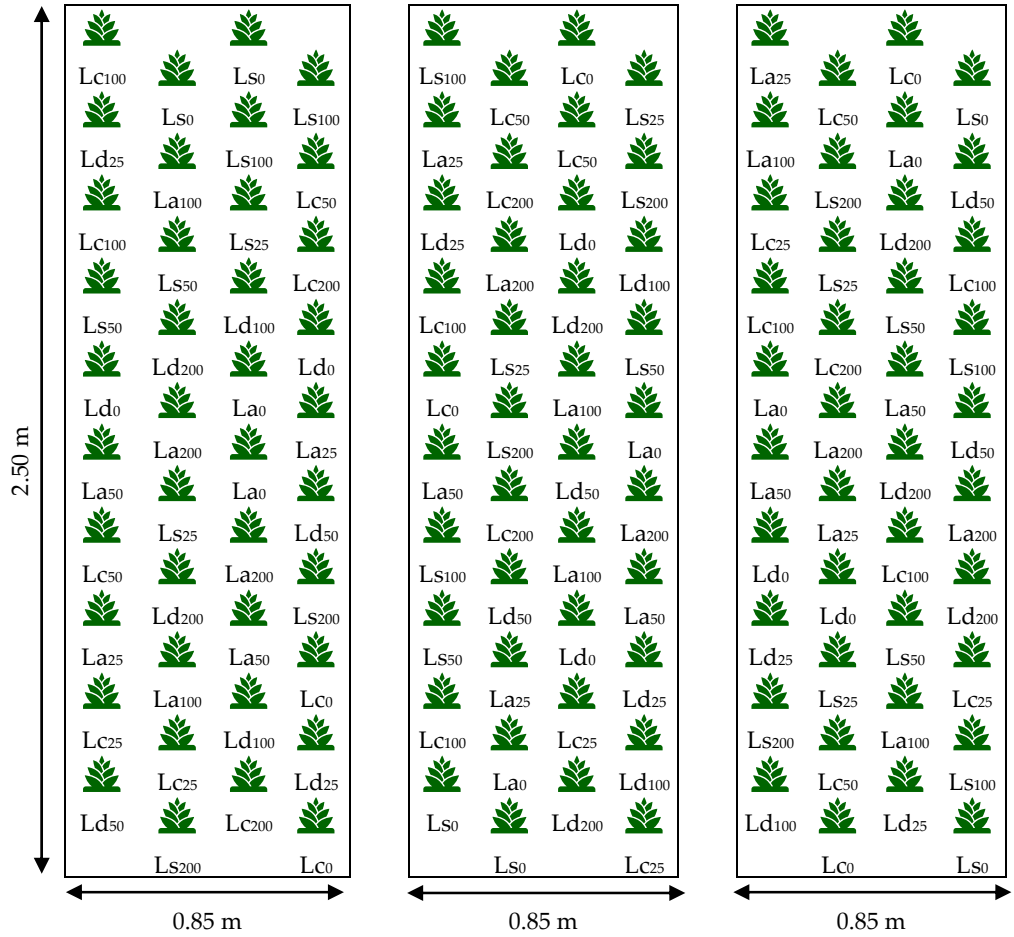

Figure 1. The layout of the experiment studying the effect of different NaCl solution irrigation treatments on the growth of 4 lavender species. Plants were arranged in a randomized complete block that consisted of 4 lavender species, 5 NaCl solution irrigation treatments (0, 25, 50, 100, 200 mM NaCl) and 6 replicates (plants) arranged in 3 blocks (metal benches; dimensions 2.50 cm length and 0.85 m width). La: *Lavandula angustifolia*, Ld: *Lavandula dentata* var. *dentata*, Lc: *Lavandula dentata* var. *candicans*, Ls: *Lavandula stoechas*, and subscripts denote applied NaCl solution irrigation treatments.

2.3. Plant Growth Variables

Measurements started one week (day 7) after irrigation with the NaCl solutions for the first time and ended 56 days later. Plant height (determined from the pot rim of the substrate surface), shoot canopy diameter (mean value of the widest width and perpendicular width), and growth index ((height + widest width + perpendicular width)/3) were measured at weekly intervals. Additionally, during flowering, for each plant, the number and length of all inflorescences that were fully open >60% as well as the corresponding peduncle length, were recorded at weekly intervals. The maximum efficiency of PSII photochemistry (Φ_{PSIIo}) of mature leaves (3 leaves per plant) was determined fortnightly (day 14, 35, 56) using a MINI-PAM Photosynthesis Yield Analyzer (Heinz Walz GmbH, Effeltrich, Germany). All measurements were performed in the morning after dark acclimation of the samples for 30 min using the saturation pulse technique. Saturation pulse (intensity circa 12,000 μmol quanta m^{-2} s^{-1}) lasted 0.8 s.

At the end of the experiment (day 56) the leaf thickness of mature leaves was determined with cross sections taken at a distance of 3 cm from the leaf base (3 leaves per plant) under a Zeiss Axiolab microscope (Carl Zeiss, Jena, Germany) using the x100 lens. Plants were harvested at the end of the experiment (day 56) and divided at soil level into shoot and root. The substrate was carefully washed off the harvested root. Following both harvested shoots and roots were separately dried in an oven at

70 °C until a constant weight was reached, and their dry weights were determined. Weekly recordings of observations for signs of salinity stress were undertaken, throughout the duration of the experiment. In plants, the onset of visual symptoms induced by salinity (leaf and stem chlorosis and necrosis) was recorded during the experiment and assessed at the end of the experiment (day 56). Visual symptoms induced by salinity were assessed on a 6 point scale from 0–5, where 0: plant mortality, 1: no leaf injury, 2: mild leaf chlorosis, 3: moderate leaf chlorosis 25–50% approximately, 4: leaf necrosis 50–75% approximately, 5: leaf necrosis >75%.

2.4. Physical-Hydraulic Properties of Substrate

A tension plate apparatus in a Haines-type assembly [25], with an air-entry value of −180 cm of a water column was employed to define the substrate water retention curve. Substrate sample sized 3 cm in height and 10.2 cm in diameter was positioned on the vibrating porous plate of a Buchner filter funnel to achieve satisfactory packing and following was subjected to gradual wetting from the bottom of the plate until saturation (for 48 h). Measurements of the water content at different pressure heads were taken to obtain the water retention curve. The retention curve was the mean of three substrate samples (n = 3).

Particle size distribution of the substrates was determined with screen analysis. Weighed substrate samples were placed in the top sieve of a column of sieves arranged from top to bottom in descending order of screen mesh size (>20.00, 16.00, 10.00, 8.00, 4.00, 2.00, 1.00, 0.50, 0.25, 0.106 and <0.053 mm) rested on a sieve shaker for 3 min at 30 shakes per minute.

2.5. Statistical Analysis

The experiment followed a randomized complete block design with two factors that constituted of four lavender species and five NaCl solution irrigation treatments. There were six replications (plants) per species and NaCl solution irrigation treatment. A two-way analysis of variance (ANOVA) was applied to test the significance of the experimental data using SPSS Statistical Software v. 17.0 (SPSS Inc., Chicago, U.S.A.), and treatment means were compared using Tukey HSD test at a probability level $p < 0.05$.

3. Results and Discussion

3.1. Physical–Hydraulic Properties of Substrate

Pressure heads of the experimental water retention curve of the substrate ranged between 0 and –100 cm providing important information concerning plant growth (Figure 2). In accordance to De Boodt and Verdonck [26], water retention in substrates with negative pressure heads greater than −100 cm decreases plant growth, while a negative pressure head that is less than −10 cm creates inadequate substrate aeration for plant growth. The main substrate hydraulic characteristics derived from the water retention curve are shown in Table 1.

Table 1. Hydraulic characteristics of the potted lavender plants' growth substrate Ps_{96}:P_4 (Ps: pure sphagnum peat and P: perlite in a 96:4 volume ratio).

Total Porosity [1] (cm^3 cm^{-3})	Airspace [2] (cm^3 cm^{-3})	Water Content at −10 cm (cm^3 cm^{-3})	Water Content at −50 cm (cm^3 cm^{-3})	Easily Available Water [3] (cm^3 cm^{-3})	Water Buffering Capacity [4] (cm^3 cm^{-3})
0.88	0.12	0.76	0.46	0.30	0.13

[1] water content at 0 cm pressure head (saturation); [2] air filled pores at −10 cm pressure head; [3] released amount of water between pressure heads of −10 and −50 cm; [4] released amount of water between pressure heads of −50 and −100 cm.

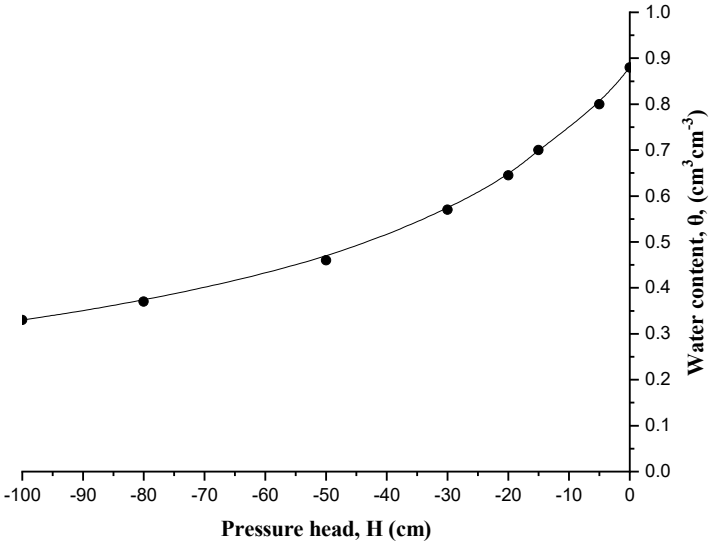

Figure 2. Water retention curve of the potted lavender plants' growth substrate Ps_{96}:P_4 (Ps: pure sphagnum peat and P: perlite in a 96:4 volume ratio).

With an aim to retain the substrate water content in the easily available water range, i.e., water content between 0.76 and 0.46 cm^3 cm^{-3} (at −10 and −50 cm pressure head, respectively) (Table 1, Figure 2), when the TDR reading reached a volumetric water content of 46%, plants were irrigated with the corresponding NaCl treatments at amounts equal to the amount lost from evapotranspiration.

Particle size distribution affects the aeration and water retention properties of substrates [27,28]. Therefore, the above retention curve was defined in part by the substrate particle size distribution that was characterized by a relatively small percentage (≈11%) of particles >8 mm, a large percentage of particles (≈61%) in the range of 8-1 mm and a moderate percentage (≈28%) of particles < 1 mm (Table 2).

Table 2. Particle size distribution of the potted lavender plants' growth substrate Ps_{96}:P_4 (Ps: pure sphagnum peat and P: perlite in a 96:4 volume ratio).

Particle Size (mm)	Particle Size Distribution (% by wt)
>20	1.24
20–16	1.18
16–10	2.09
10–8	6.70
8–4	18.19
4–2	20.79
2–1	21.85
1–0.5	11.22
0.5–0.25	7.18
0.25–0.106	3.94
0.106–0.053	2.72
<0.053	2.90

3.2. Symptoms Induced by Salinity

Indicator of the effect of salinity are the visible symptoms of the induced damage in plants (such as leaf chlorosis, browning and necrosis) that affects plant ornamental value [29]; an important consideration in floriculture [30]. Throughout the experiment, there was no plant mortality. At the high concentrations of 100 and 200 mM NaCl, all species demonstrated signs of salinity stress expressed initially with chlorosis of the leaves located at the middle and base of the plants followed by gradual necrosis of leaves and stems; at the end of the experiment (day 56), all lavender species irrigated with

200 mM NaCl had leaf necrosis >75% (Table 3). When irrigated with 100 mM NaCl, symptoms of leaf necrosis were more intense in both *Lavandula angustifolia* and *L. stoechas* than in both *L. dentata* var. *dentata* and *L. dentata* var. *candicans*. *L. stoechas* was the first species to demonstrate salinity stress (approximately 28 days since the start of the experiment), followed a week later by *L. angustifolia* and a further week later by both *L. dentata* var. *candicans* and *L. dentata* var. *dentata* (data not shown). On the other hand, all species irrigated with 50 mM NaCl demonstrated moderate signs of salinity stress at completion of the experiment expressed with chlorosis of the leaves (25%–50%) located at the middle and base of the plants; these symptoms reduce the commercial value of the plants. Furthermore, at 25 mM NaCl leaf chlorosis was inconspicuous in all species. Additionally, during the experiment it was noted that only the control of *L. dentata* var. *dentata* demonstrated mild signs of chlorosis suggesting nutrient deficiency; generally, *L. dentata* var. *dentata* developed greater growth (see Section 2.2) in comparison to the other species, therefore, is possible to have had a greater demand for nutrients.

Table 3. Assessment of visual symptoms of potted lavender plants induced by salinity based on a 6-point scale (0–5).

	NaCl Solution				
Species	**0 mM (Control)**	**25 mM**	**50 mM**	**100 mM**	**200 mM**
L. angustifolia	1*	2	3	5	5
L. stoechas	1	2	3	5	5
L. dentata var. *candicans*	1	2	3	4.0	5
L. dentata var. *dentata*	1.5	2	3	4.5	5

where, 0: plant mortality, 1: no leaf injury, 2: mild leaf chlorosis <25%, 3: moderate leaf chlorosis 25%–50% approximately, 4: leaf necrosis 50%-75% approximately, 5: leaf necrosis >75%.

Moderate symptoms of salinity at 50 mM suggest the need for further research to establish the effect of salinity in the range of 25–50 mM NaCl. The use of good quality water between saline water irrigations for strategic leaching of salts could contribute to reducing or delaying the effect of salinity [31]. To further reduce the use of good quality water natural resources for irrigation further research, studying the possibility of strategic leaching of salts with good quality water between saline water irrigations (>50 mM) is also suggested. Overall symptoms were more apparent in *L. dentata* var. *dentata* and *L. stoechas* due to the natural green color foliage of the particular species compared to the natural grey-green foliage of the other two species. Concerning *L. angustifolia* the above symptoms of plants irrigated with 100 and 200 mM NaCl (10.6 dSm^{-1} and 20.7 dSm^{-1}, respectively) were obtained after 56 days of irrigation leading to plant death if the experiment was prolonged further and were similar to the results obtained by Niu and Rodriguez [32] for *L. angustifolia* pot grown plants in peat-perlite based substrate and under greenhouse conditions after 11 weeks of irrigation with NaCl solutions; plants irrigated with 0.8 dS m^{-1} showed good quality with acceptable reduction growth and little leaf injury, whereas plants irrigated with 3.2 dS m^{-1} showed stunted growth and moderate leaf injury (25%–50%), while plants irrigated with either 6.4 dS m^{-1} or 12.0 dS m^{-1} died.

3.3. Plant Growth

With the exception of measurements taken near completion of the experiment (42 and 49 days) in all four species, two-way ANOVA for data concerning the various plant growth variables measured throughout the duration of the experiment showed no significant interactions of the main experimental factors that are between species and irrigated NaCl solutions. In most measured plant variables (plant height, shoot canopy diameter, growth index, Φ_{PSIIo}, inflorescence number) there was a significant effect of the main factors from the beginning of the experiment until day 42. Significant interactions were shown on day 49 and 56 for plant height, day 35 and 56 for Φ_{PSIIo} and at the end of the experiment (day 56) for leaf thickness, inflorescence number and length, peduncle length and root dry weight.

Overall results confirm that salinity stress is initially expressed in the above ground growth parameter of plants [33]. More specifically, plant height was significantly reduced at 200 mM NaCl from day 21 onwards and until day 42 (Table 4). Overall *L. angustifolia* showed the smallest height while *L.* dentata var. *dentata* showed the greatest plant height ($p < 0.05$) between day 7 and 42. Both *L. stoechas* and *L. dentata* var. *candicans* showed similar development in plant height between them that was intermediate of the other two species ($p < 0.05$). Following, near completion of the experiment (days 49 and 56) *L. angustifolia* continued to show the least plant height compared to the other species. On both day 49 and day 56, plant height at 200 mM NaCl was significantly reduced compared to the control in *L. stoechas* and *L. dentata* var. *candicans.* Furthermore, on day 56, plant height at both 100 and 200 mM NaCl was significantly reduced compared to the control in *L. dentata* var. *dentata.* Our results agree with previous research findings that showed salinity induced the decrease in plant height of pot grown *Arbutus unedo* in peat, sand and clay-loam based substrate and irrigated for 16 weeks with 52 mM and 105 mM [34].

Similar results to plant height were obtained for shoot canopy diameter. Shoot canopy diameter was reduced significantly at both 100 and 200 mM NaCl compared to the control from day 49 of the experiment onwards (Table 5). Overall *L. angustifolia* showed the smallest shoot canopy diameter while *L. dentata var. dentata* the greatest one throughout the duration of the experiment ($p < 0.05$). *L. dentata* var. *candicans* showed a similar development in shoot canopy diameter with *L. dentata var. dentata* until day 35; afterwards, it showed a similar shoot canopy development with *L. stoechas* that was between that of the other two species ($p < 0.05$). Results were also consistent for the plant growth index. Plant growth index was reduced significantly at 200 mM NaCl compared to the control from day 35 of the experiment onwards (Table 6). Overall *L. angustifolia* showed the smallest growth index while *L. dentata var. dentata* the greatest one throughout the duration of the experiment ($p < 0.05$). *L. dentata* var. *candicans* showed a similar growth index with *L. dentata var. dentata* on day 7. Afterwards, it showed a similar growth index with *L. stoechas* that was between that of the other two species ($p < 0.05$). Similarly, in our results, the canopy and biomass of both *Cistus albidus* and *C. monspeliensis* grown in pots containing peat-pelite based substrate were reduced after 4 months irrigation with 70 and 140 mM NaCl [35]. Also, the canopy and biomass of potted *Asteriscus maritimus* in peat and sand based substrate were reduced after 150 days of irrigation with 70 and 140 mM NaCl [33].

A decrease in shoot dry weight is also an initial effect of reduced growth due to salinity [31]. Shoot dry weight was significantly reduced compared to the control at both 100 and 200 mM NaCl (Table 7). In a similar experiment, the total plant dry weight of *L. multifida* decreased when irrigated with 100 mM and 200 mM NaCl [20,24]. Both *L. dentata* var. *dentata* and *L. dentata* var. *candicans* developed similar shoot dry weights that were significantly greater than the other two species. Furthermore *L. angustifolia* developed the smallest shoot dry weight amongst the studied species ($p < 0.05$). It is possible that there is the presence of some interspecies variation, as the salinity shoot dry weight decrease of the corresponding control at 200 mM was the smallest for *L. angustifolia* (3%), followed in ascending order by *L. dentata* var. *candicans* (18%), *L. dentata* var. *dentata* (27%) and *L. stoechas* (32%). Although *L. angustifolia* (3%) showed the least decrease in shoot dry weight from the corresponding control, the appearance of the plant at the end of the experiment in comparison to the other species exhibited a large amount of leaf and stem necrosis at both 100 mM and 200 mM NaCl (see Section 2.1). The above results agree with the decrease in shoot dry weight due to irrigation with NaCl solutions in other pot grown ornamental species under greenhouse conditions such as *Nerium oleander* [36], *Achillea millefolium*, *Agastache cana*, *Gaillardia aristata* [37], and *Rosmarinus officinalis* [38]. On the other hand, although root dry weight in all species increased at low NaCl concentrations followed by a decrease at 100 and 200 mM NaCl, root dry weights compared to the control were not significantly different. As there were non-significant differences between the control and various NaCl solutions, it is possible that *L. dentata* var. *candicans* developed the greatest root dry weight, while the other species developed similar root dry weights ($p < 0.05$) due to interspecies variation.

Table 4. The effect of irrigation with different NaCl solutions on plant height (cm) of *Lavandula* species (n = 6, $p < 0.05$). Differences between means ± S.E. shown with different letters (Tukey HSD, $p < 0.05$).

	Day	7	14	21	28	35	42	49	56
Species									
L. angustifolia		16.467 ± 0.456c	18.047 ± 0.389c	18.583 ± 0.408c	19.063 ± 0.405c	19.257 ± 0.390c	19.267 ± 0.412c	-†	-
L. stoechas		25.700 ± 0.456b	28.510 ± 0.389b	29.023 ± 0.408b	29.657 ± 0.405b	30.463 ± 0.390b	31.810 ± 0.412b	-	-
L. dentata var *candicans*		25.583 ± 0.456b	27.410 ± 0.389b	28.207 ± 0.408b	28.900 ± 0.405b	29.280 ± 0.390b	29.623 ± 0.412b	-	-
L. dentata var. *dentata*		29.767 ± 0.456a	33.327 ± 0.389a	34.617 ± 0.408a	36.237 ± 0.405a	37.603 ± 0.390a	38.840 ± 0.412a	-	-
NaCl (mM)									
0 mM (control)		ns	ns	27.779 ± 0.456ab	28.825 ± 0.453a	29.983 ± 0.436a	31.463 ± 0.461a	-	-
25 mM		ns	ns	27.763 ± 0.456ab	28.850 ± 0.453a	29.450 ± 0.436a	30.275 ± 0.461ab	-	-
50 mM		ns	ns	28.525 ± 0.456a	29.392 ± 0.453a	30.271 ± 0.436a	30.829 ± 0.461a	-	-
100 mM		ns	ns	27.467 ± 0.456ab	28.213 ± 0.453ab	28.604 ± 0.436ab	28.904 ± 0.461bc	-	-
200 mM		ns	ns	26.504 ± 0.456b	27.042 ± 0.453b	27.446 ± 0.436b	27.954 ± 0.461c	-	-
Interaction (species x NaCl)									
L. angustifolia x	0 mM (control)	ns	ns	ns	ns	ns	ns	18.817 ± 0.936i	18.817 ± 0.985j
	25 mM	ns	ns	ns	ns	ns	ns	19.300 ± 0.936i	19.300 ± 0.985j
	50 mM	ns	ns	ns	ns	ns	ns	19.683 ± 0.936i	19.817 ± 0.985j
	100 mM	ns	ns	ns	ns	ns	ns	20.083 ± 0.936i	20.083 ± 0.985j
	200 mM	ns	ns	ns	ns	ns	ns	18.367 ± 0.936i	18.367 ± 0.985j
L. stoechas x	0 mM (control)	ns	ns	ns	ns	ns	ns	35.950 ± 0.936bcde	36.283 ± 0.985cdef
	25 mM	ns	ns	ns	ns	ns	ns	32.483 ± 0.936cdefg	32.950 ± 0.985defgh
	50 mM	ns	ns	ns	ns	ns	ns	33.500 ± 0.936cdef	33.750 ± 0.985defg
	100 mM	ns	ns	ns	ns	ns	ns	31.400 ± 0.936efgh	31.400 ± 0.985fghi
	200 mM	ns	ns	ns	ns	ns	ns	29.567 ± 0.936fgh	29.567 ± 0.985ghi
L. dentata var. *candicans* x	0 mM (control)	ns	ns	ns	ns	ns	ns	32.100 ± 0.936defg	32.517 ± 0.985defgh
	25 mM	ns	ns	ns	ns	ns	ns	30.600 ± 0.936fgh	30.600 ± 0.985ghi
	50 mM	ns	ns	ns	ns	ns	ns	31.633 ± 0.936efgh	31.633 ± 0.985efgh
	100 mM	ns	ns	ns	ns	ns	ns	27.950 ± 0.936gh	27.950 ± 0.985hi
	200 mM	ns	ns	ns	ns	ns	ns	27.183 ± 0.936h	26.467 ± 0.985i
L. dentata var. *dentata* x	0 mM (control)	ns	ns	ns	ns	ns	ns	41.600 ± 0.936a	42.183 ± 0.985a
	25 mM	ns	ns	ns	ns	ns	ns	40.917 ± 0.936a	41.500 ± 0.985ab
	50 mM	ns	ns	ns	ns	ns	ns	40.333 ± 0.936ab	40.333 ± 0.985abc
	100 mM	ns	ns	ns	ns	ns	ns	36.833 ± 0.936abcd	36.933 ± 0.985bcd
	200 mM	ns	ns	ns	ns	ns	ns	36.983 ± 0.936abc	36.517 ± 0.985bcde
$F_{species}$/sig.		151.694/0.000*	270.206/0.000*	266.763/0.000*	305.079/0.000*	375.767/0.000*	386.198/0.000*	397.793/0.000	364.676/0.000
F_{NaCl}/sig.		2.158/0.079	1.641/0.170	2.568/0.043*	3.926/0.005*	6.909/0.000*	9.685/0.000*	12.834/0.000	14.908/0.000
$F_{interaction}$/sig.		0.981/0.472	1.135/0.341	0.740/0.709	0.695/0.753	1.272/0.247	1.374/0.191	1.856/0.049*	1.961/0.036*

ns: non-significant; * denotes significant differences between means at $p < 0.05$, shown with different letters within columns. †When interactions are significant, factors are not considered and mean values are not shown.

Table 5. The effect of irrigation with different NaCl solutions on shoot canopy diameter (cm) of *Lavandula* species (n = 6, $p < 0.05$). Differences between means ± S.E. shown with different letters (Tukey HSD, $p < 0.05$).

Day	**7**	**14**	**21**	**28**	**35**	**42**	**49**	**56**
Species								
L. angustifolia	15.940 ± 0.413c	18.747 ± 0.441c	19.473 ± 0.417c	19.903 ± 0.418c	20.037 ± 0.412c	20.407 ± 0.415c	20.510 ± 0.418c	20.533 ± 0.419c
L. stoechas	21.890 ± 0.413b	26.647 ± 0.441b	27.600 ± 0.417b	28.330 ± 0.418b	29.173 ± 0.412b	29.950 ± 0.415b	30.417 ± 0.418b	30.417 ± 0.419b
L. dentata var. *candicans*	27.233 ± 0.413a	31.457 ± 0.441a	32.873 ± 0.417a	33.840 ± 0.418a	34.097 ± 0.412a	34.427 ± 0.415b	34.473 ± 0.418b	34.473 ± 0.419b
L. dentata var. *dentata*	26.350 ± 0.413a	31.750 ± 0.441a	32.603 ± 0.417a	34.477 ± 0.418a	35.203 ± 0.412a	37.160 ± 0.415a	37.797 ± 0.418a	37.863 ± 0.419a
NaCl (mM)								
0 mM (control)	ns	ns	ns	ns	ns	ns	32.021 ± 0.467a	32.117 ± 0.469a
25 mM	ns	ns	ns	ns	ns	ns	31.063 ± 0.467ab	31.079 ± 0.469ab
50 mM	ns	ns	ns	ns	ns	ns	31.125 ± 0.467ab	31.125 ± 0.469ab
100 mM	ns	ns	ns	ns	ns	ns	30.163 ± 0.467b	30.163 ± 0.469b
200 mM	ns	ns	ns	ns	ns	ns	29.625 ± 0.467b	29.625 ± 0.469b
$F_{species}$/sig.	156.673/0.000*	189.365/0.000*	226.035/0.000*	260.722/0.000*	280.935/0.000*	313.565/0.000*	321.313/0.000*	320.620/0.000*
F_{NaCl}/sig.	1.289/0.280	0.536/0.710	0.395/0.811	1.518/0.203	1.315/0.270	1.933/0.111	3.950/0.005*	4.215/0.003*
$F_{interaction}$/sig.	1.302/0.229	0.243/0.995	0.382/0.967	1.305/0.228	0.556/0.872	0.528/0.892	0.635/0.808	0.656/0.789

ns: non-significant; * denotes significant differences between means at $p < 0.05$, shown with different letters within columns.

Table 6. The effect of irrigation with different NaCl solutions on plant growth index of *Lavandula* species (n = 6, $p < 0.05$). Differences between means ± S.E. shown with different letters (Tukey HSD, $p < 0.05$).

Day	**7**	**14**	**21**	**28**	**35**	**42**	**49**	**56**
Species								
L. angustifolia	16.100 ± 0.335c	18.493 ± 0.323c	19.157 ± 0.318c	19.617 ± 0.327c	19.767 ± 0.309c	20.010 ± 0.318c	20.073 ± 0.329c	20.097 ± 0.333c
L. stoechas	23.153 ± 0.335b	27.250 ± 0.323b	28.067 ± 0.318b	28.760 ± 0.327b	29.593 ± 0.309b	30.553 ± 0.318b	31.110 ± 0.329b	31.187 ± 0.333b
L. dentata var. *candicans*	26.687 ± 0.335a	30.087 ± 0.323b	31.297 ± 0.318b	32.173 ± 0.327b	32.480 ± 0.309b	32.807 ± 0.318b	32.927 ± 0.329b	32.910 ± 0.333b
L. dentata var. *dentata*	27.483 ± 0.335a	32.263 ± 0.323a	33.253 ± 0.318a	34.720 ± 0.327a	35.993 ± 0.309a	37.710 ± 0.318a	38.310 ± 0.329a	38.407 ± 0.333a
NaCl (mM)								
0 mM (control)	ns	ns	ns	ns	30.296 ± 0.345a	31.300 ± 0.356a	32.038 ± 0.367a	32.213 ± 0.372a
25 mM	ns	ns	ns	ns	29.617 ± 0.345ab	30.492 ± 0.356ab	30.967 ± 0.367ab	31.071 ± 0.372ab
50 mM	ns	ns	ns	ns	29.821 ± 0.345ab	30.825 ± 0.356ab	31.171 ± 0.367ab	31.204 ± 0.372ab
100 mM	ns	ns	ns	ns	28.996 ± 0.345ab	29.717 ± 0.356bc	29.775 ± 0.367bc	29.783 ± 0.372bc
200 mM	ns	ns	ns	ns	28.563 ± 0.345b	29.017 ± 0.356c	29.075 ± 0.367c	28.979 ± 0.372c
$F_{species}$/sig.	239.689/0.000*	351.413/0.000*	384.017/0.000*	406.690/0.000*	224.500/0.000*	550.696/0.000*	542.787/0.000*	532.256/0.000*
F_{NaCl}/sig.	0.464/0.762	0.138/0.968	0.948/0.440	2.267/0.067	3.933/0.049*	6.514/0.000*	10.242/0.000*	11.675/0.000*
$F_{interaction}$/sig.	0.862/0.587	0.431/0.948	0.619/0.822	0.962/0.490	0.922/0.528	0.860/0.590	1.139/0.338	1.256/0.257

ns: non-significant; * denotes significant differences between means at $p < 0.05$, shown with different letters within columns.

Table 7. The effect of irrigation with different NaCl solutions on shoot and root dry weights (g) of *Lavandula* species (n = 6, $p < 0.05$). Differences between means ± S.E. shown with different letters (Tukey HSD, $p < 0.05$).

		Shoot	Root
Species			
L. angustifolia		20.638 ± 0.950c	-†
L. stoechas		34.428 ± 0.950b	-
L. dentata var. *candicans*		47.178 ± 0.950a	-
L. dentata var. *dentata*		43.854 ± 0.650a	-
NaCl (mM)			
0 mM (control)		41.270 ± 1.062a	-
25 mM		36.907 ± 1.062 b	-
50 mM		37.534 ± 1.062ab	-
100 mM		34.974 ± 1.062bc	-
200 mM		31.937 ± 1.062c	-
Interaction (species x NaCl)			
L. angustifolia x	0 mM (control)	ns	5.917 ± 0.501cd
	25 mM	ns	6.282 ± 0.501c
	50 mM	ns	4.865 ± 0.501cd
	100 mM	ns	4.985 ± 0.501cd
	200 mM	ns	5.123 ± 0.501cd
L. stoechas x	control	ns	5.593 ± 0.501cd
	25 mM	ns	6.417 ± 0.501c
	50 mM	ns	4.752 ± 0.501cd
	100 mM	ns	5.575 ± 0.501cd
	200 mM	ns	3.488 ± 0.501d
L. dentata var. *candicans* x	0 mM (control)	ns	13.887 ± 0.501ab
	25 mM	ns	14.847 ± 0.501ab
	50 mM	ns	15.180 ± 0.501a
	100 mM	ns	15.422 ± 0.501a
	200 mM	ns	12.277 ± 0.501b
L. dentata var. *dentata* x	0 mM (control)	ns	5.315 ± 0.501cd
	25 mM	ns	4.800 ± 0.501cd
	50 mM	ns	5.533 ± 0.501cd
	100 mM	ns	4.667 ± 0.501cd
	200 mM	ns	4.703 ± 0.501cd
$F_{species}$/sig.		156.577/0.000*	415.648/0.000
F_{NaCl}/sig.		10.444/0.000*	6.470/0.000
$F_{interaction}$/sig.		1.312/0.223	2.396/0.009*

ns: non-significant; * denotes significant differences between means at $p < 0.05$, shown with different letters within columns. †When interactions are significant, factors are not considered, and mean values are not shown.

Leaf thickening is a common response to salinity [31,39], whereby salt content in the leaves is diluted by increased succulence [40]. Leaf thickness increased significantly compared to the control only in *L. angustifolia* at 50 mL NaCl (Figure 3); however, non-significant leaf thickness increase compared to the control was generally observed at concentrations >50 mM NaCl in the remaining lavender species. It is possible over the 56 days, NaCl levels, especially in the higher concentrations (100 and 200 mM NaCl), exceeded the threshold of long-term acclimation mechanisms related to leaf thickness. Further research with smaller NaCl levels is necessary to study the effect of salinity on leaf thickness.

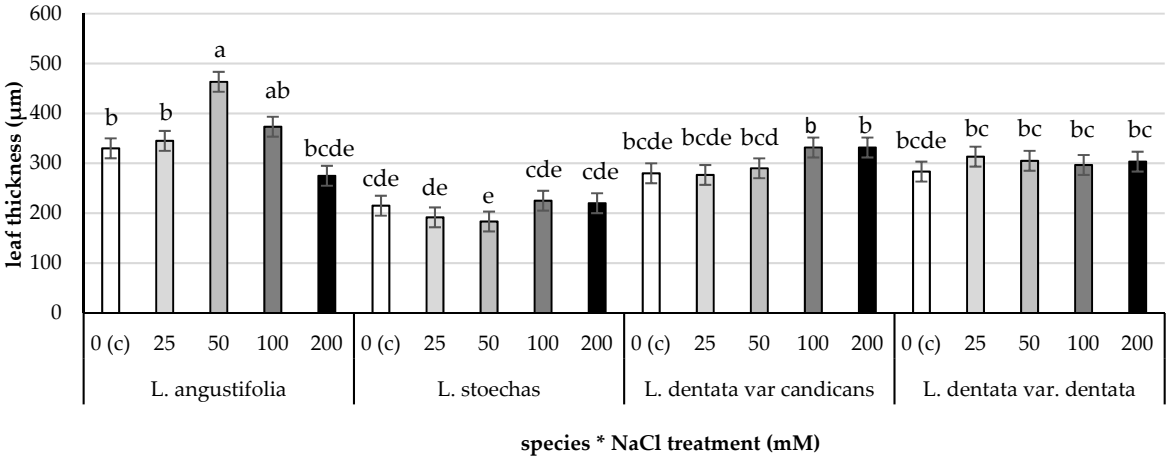

Figure 3. The combined effect of the interaction between lavender species and NaCl solution irrigation treatments (0, 25, 50, 100, 200 mM) on leaf thickness of plants (n = 6, $p < 0.05$). Differences between means ± S.E. shown with different letters (Tukey HSD, $p < 0.05$). Note c: control.

A secondary effect of reduced growth induced by salinity includes the potential reduction in photosynthesis of plant leaves [16]. Concerning Φ_{PSIIo}, *L. dentata* var. *dentata* showed the least Φ_{PSIIo} compared to the other species ($p < 0.05$) on day 14 (Table 8), suggesting the presence of interspecies variation in plant nutrient demand, as there were non-significant differences between the control and the different NaCl solutions applied and the fact that *L. dentata* var. *dentata* Φ_{PSIIo} values in the control (0.77) were relatively less than optimum (circa 0.83) [41]. With regards to the latter, *L. dentata* var. *dentata* also showed mild signs of chlorosis in the control, suggesting a greater demand for nutrients in comparison to the other species (see Section 2.1). Following this, Φ_{PSIIo} significantly decreased in plants irrigated with 200 mM NaCl compared to the control on day 35 only in *L. angustifolia*, and on day 56 in both *L. angustifolia* and *L. dentata* var. *candicans*. The Φ_{PSIIo} values for all species irrigated with 200 NaCl was lower than the optimum Φ_{PSIIo} value for most plant species (circa 0.83), indicating the exposure of plants to stress, in this study salt stress [41]. Although no significant differences were shown, the remaining Φ_{PSIIo} values of plants irrigated with either 100 mM or 200 mM were also less than the optimum Φ_{PSIIo} in all species. The decrease in Φ_{PSIIo} suggests the presence of salt stress that led to chlorosis and premature senescence of mature leaves [42]. These results agree with the symptoms or leaf chlorosis and necrosis observed on the plants irrigated with 100 and 200 mM NaCl and also with Munns' [43] findings that high potassium concentrations cause premature senescence, chlorosis, and necrosis in leaves due to the disrupt of plant protein synthesis.

Plants subjected to salt stress could reduce the inflorescence number, influence flowering time (speed or delay) and duration, reduce inflorescence and reduce peduncle length. Throughout the duration of the experiment, only two lavender species flowered (*L. stoechas* and *L. dentata* var. *dentata*). The experiment took place in late winter–early spring (Feb-March) and as the control of both non-flowered lavenders (*L. angustifolia* and *Lavandula dentata* var. *candicans*) did not produce inflorescences, it is possible that the season in which the experiment took place was too early for these species to flower. It is reported that *L. dentata* var. *dentata* flower all year round in mild-winter areas such as Athens [44] and *L. stoechas* flowers in early spring [45], whereas *L. dentata* var. *candicans* from early spring to late fall and *L. angustifolia* flowers from early to midsummer [44]. Anthesis in both *L. stoechas* and *L. dentata* var. *dentata* started earlier at 100 and 200 mM NaCl compared to the control (Figure 4). At the end of the experiment (day 56), the inflorescence number for the two lavender species that flowered was reduced significantly at 100 and 200 mM in comparison to the control only for *L. stoechas*, suggesting a tendency for earlier inflorescence death under salt stress. Similarly, the inflorescence length was reduced significantly at 100 and 200 mM only for *L. stoechas*. On the other hand, the inflorescence peduncle was reduced significantly compared to the control in

all NaCl concentrations for both flowered *L. stoechas* and *L. dentata* var. *dentata*. The above results agree with the findings of several authors that have studied the effect of salinity on various ornamental plant species. García-Caparrós and Lao [46] state that salinity could bring forward and shorten the duration of anthesis. Salinity has been reported to decrease the inflorescence number in gerbera [47,48], different cultivars of *Rosa* x *hybrida* L. [48,49], *Matricaria chamomilla* [50], inflorescence length in *Eustoma grandiflorum* [18] as well as the peduncle length / stem length (measured from the basis of the plant to the first flower) in *Dianthus caryophyllus*, *Gerbera jamesonii* L [47], *Eustoma grandiflorum* [18], *Rosa hybrida* 'Kardinal' [51], and *Matricaria chamomilla* [50]. Results also showed that *Lavandula stoechas* developed significantly more inflorescences than *L. dentata* var. *dentata* on both day 42 and 49, which is possibly due to interspecies differences, as there were no differences between the control and applied NaCl solutions.

Table 8. The effect of irrigation with different NaCl solutions on leaf Φ_{PSII_o} of *Lavandula* species (n = 6, $p < 0.05$). Differences between means ± S.E. shown with different letters (Tukey HSD, $p < 0.05$).

	Day	14	35	56
Species				
L. angustifolia		0.821 ± 0.007a	-†	-
L. stoechas		0.807 ± 0.007a	-	-
L. dentata var. *candicans*		0.810 ± 0.007a	-	-
L. dentata var. *dentata*		0.755 ± 0.007b	-	-
NaCl (mM)				
0 mM (control)		ns	-	-
25 mM		ns	-	-
50 mM		ns	-	-
100 mM		ns	-	-
200 mM		ns	-	-
Interaction (species x NaCl)				
L. angustifolia x	0 mM (control)	ns	0.788 ± 0.056a	0.821 ± 0.075a
	25 mM	ns	0.816 ± 0.056a	0.833 ± 0.075a
	50 mM	ns	0.789 ± 0.056a	0.794 ± 0.075a
	100 mM	ns	0.674 ± 0.056a	0.500 ± 0.075abc
	200 mM	ns	0.160 ± 0.056b	0.215 ± 0.075bc
L. stoechas x	0 mM (control)	ns	0.815 ± 0.056a	0.832 ± 0.075a
	25 mM	ns	0.790 ± 0.056a	0.798 ± 0.075a
	50 mM	ns	0.797 ± 0.056a	0.775 ± 0.075a
	100 mM	ns	0.723 ± 0.056a	0.470 ± 0.075abc
	200 mM	ns	0.566 ± 0.056a	0.493 ± 0.075abc
L. dentata var. *candicans* x	0 mM (control)	ns	0.821 ± 0.056a	0.807 ± 0.075a
	25 mM	ns	0.820 ± 0.056a	0.821 ± 0.075a
	50 mM	ns	0.796 ± 0.056a	0.828 ± 0.075a
	100 mM	ns	0.748 ± 0.056a	0.631 ± 0.075a
	200 mM	ns	0.728 ± 0.056a	0.130 ± 0.075c
L. dentata var. *dentata* x	0 mM (control)	ns	0.770 ± 0.056a	0.788 ± 0.075a
	25 mM	ns	0.743 ± 0.056a	0.731 ± 0.075a
	50 mM	ns	0.717 ± 0.056a	0.767 ± 0.075a
	100 mM	ns	0.632 ± 0.056a	0.585 ± 0.075ab
	200 mM	ns	0.660 ± 0.056a	0.523 ± 0.075ab
$F_{species}$/sig.		19.181/0.000*	5.358/0.000	0.450/0.718
F_{NaCl}/sig.		0.352/0.842	16.579/0.000	30.580/0.000
$F_{interaction}$/sig.		1.061/0.401	4.322/0.000*	1.959/0.036*

ns: non-significant; * denotes significant differences between means at $p < 0.05$, shown with different letters within columns. † When interactions are significant, factors are not considered, and mean values are not shown.

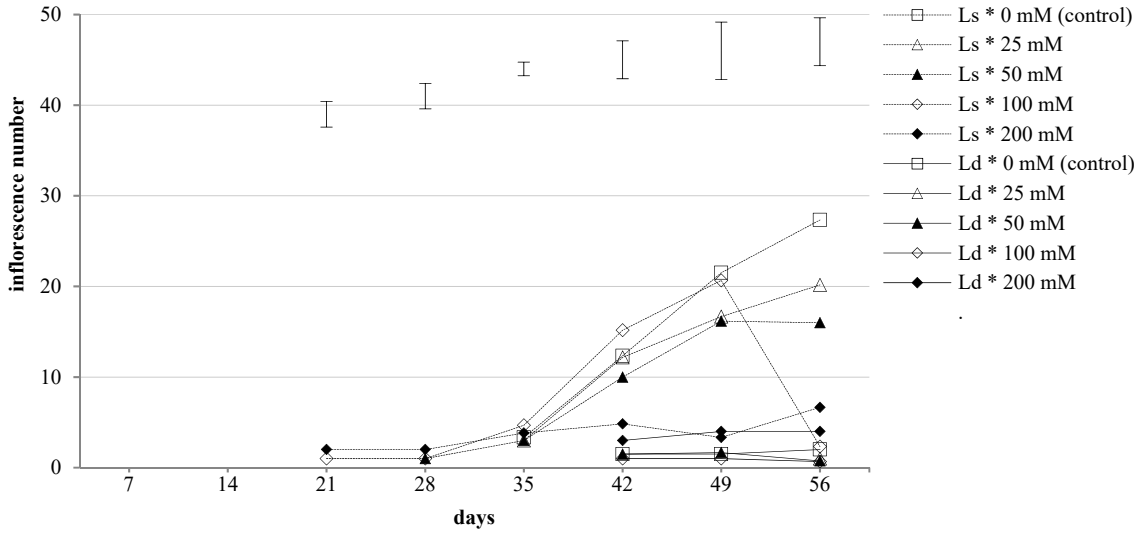

Figure 4. The combined effect of the interaction between lavender species and NaCl solution irrigation treatments (0, 25, 50, 100, 200 mM) on plant inflorescence number (n = 6, $p < 0.05$). Note: Ls: *L. stoechas*, Ld: *L. dentata* var. *dentata*. Bars represent S.E.

Considering all of the above, the overall performance of the studied lavender species under the effect of salinity was satisfactory at levels <25 mM NaCl in all species. Further research is necessary to establish the effect of salinity between 25–50 mM NaCl or possibly >50 mM in combination with the interchanged use of irrigation with good quality water with the aim to contribute towards the conservation of good quality water natural resources. The adverse effects induced by high levels of NaCl (>100 mM) amongst lavender species in ascending order was *Lavandula dentata* var. *dentata*, *L. dentata* var. *candicans*, *L. stoechas* and *L. angustifolia*. Therefore, in areas with saline irrigation water, the use of the better performed in the current study under saline irrigation conditions *Lavandula dentata* var. *dentata* and *L. dentata* var. *candicans* is proposed.

4. Conclusions

The study of the effect of saline irrigation in floriculture is important to consider for producing nursery crops without signs of salinity injury. Amongst other factors, the level of salinity stress induced on plants is dependent on plant species and varieties. The effect of salinity through irrigation on the growth of four lavender species was determined. The applied irrigation method allowed plants to receive the adequate amount of water for plant growth (easily available water), ensuring the effect of irrigation was induced by water quality i.e., applied NaCl solutions.

The effect of salinity was initially expressed in most of the above ground growth variables of the plants studied. Generally, growth was satisfactory in all species irrigated with <25 mM NaCl. Symptoms of salinity injury were moderate at 50 mM NaCl, affecting the commercial value of the ornamental species. At high NaCl levels (100 and 200 mM), plants showed severe symptoms of salt stress that included leaf and stem necrosis. Only two lavender species flowered, possibly due to season variation between species. Anthesis time was quicker and anthesis duration was reduced for plants irrigated with high saline concentrations.

Overall results of the effect of salinity were consistent, allowing to rank species in descending order of plant development as follows: *Lavandula dentata* var. *dentata*, *L. dentata* var. *candicans*, *L. stoechas* and *L. angustifolia*. Throughout the duration of the experiment, both *Lavandula dentata* var. *dentata* and *L. dentata* var. *candicans* showed better growth, and hence are suggested for areas with poor water quality using saline water for irrigation.

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editing, A.T.P., P.A.L., G.L. and K.B.; supervision, A.T.P., P.A.L. and G.L.; project administration, A.T.P. A.K.K. and K.B. All authors have read and agreed to the published version of the manuscript.

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