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Effects of Salinity on the Macro- and Micronutrient Contents of a Halophytic Plant Species (*Portulaca oleracea* L.)

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Abstract: The main purpose of the two consecutive experimental studies presented here was to compare the effect of salinity on nutrients in leaves of the halophytic plant species *Portulaca oleracea* L. and in soil. The first experiment was conducted to study the effect of salinity on plant growth, biomass accumulation, yield, root layer development, salt accumulation, and the dynamics of changes in mineral substances in plants and soil. In the second experiment, *P. oleracea* seeds were sown directly into salinized soil (treated immediately before plant growth) to determine the nutrient levels in leaves and soil. Three salinity treatments (saline water solution with NaCl: T1, 5 dS m^{-1}; T2, 9.8 dS m^{-1}; and T3, 20 dS m^{-1}) and a control treatment (T0, 1 dS m^{-1}) were used in the first experiment. The soil in the second experiment was used in a previous study (performed immediately before *P. oleracea* growth) (salinized soil: T1, 7.2 dS m^{-1}; T2, 8.8 dS m^{-1}; T3, 15.6 dS m^{-1}; T0, 1.9 dS m^{-1}). The plants were irrigated with tap water at amounts in the range of 0.25–0.50 L/pot. Analysis of the experimental results showed that *P. oleracea* is resistant to salinity, is able to remove ions (400–500 kg ha^{-1} NaCl), and can be grown in saline soil. The results indicated that *P. oleracea* is able to grow in high-salinity soil. This finding was confirmed by the dry matter obtained under high-salinity conditions. Salinity stress affected nutrient uptake in leaves and soil.

Keywords: nutrients; halophytic; saline soil; biomass accumulation; salt accumulation

1. Introduction

Purslane has long been known to be a highly nutritious leafy vegetable particularly with respect to high levels of omega-3 fatty acids. Thus, preventing the accumulation of non-nutritional compounds will allow plants to be grown in saline conditions as crops [1]. Purslane (*Portulaca oleracea* L.) is the eighth most common plant distributed throughout the world, because it is an important heat- and drought-tolerant vegetable crop [2]. Purslane (*Portulaca oleracea*) is a drought- and salt-tolerant annual plant that contains high amounts of beneficial antioxidant vitamins and minerals. The effect of salt stress on the growth and mineral composition of purslane (*Portulaca oleracea* L.) was studied [3]. The 'weed' purslane (*Portulaca oleracea* L.) is gaining special attention by agriculturists and nutritionists. It is a common weed in turfgrass areas as well as field crop areas [4,5].

The experiment was conducted to study the effect of salinity on plant growth, biomass accumulation, yield, root development, salt accumulation, and the dynamics of changes in mineral substances in plants and soil.

The other research was to determine by Franco [6] the effects of salinity, by means of exposure to different concentrations of NaCl in the nutrient solution, on the germination, growth, yield, and nitrate contents of purslane cultivated in a hydroponic system under two different light intensities. Another scientific study was initiated to evaluate the interactive effects of sulfate salinity and selenium on biomass production and mineral content of purslane (*Portulaca oleracea*) [7].

Salinity stress causes an imbalance in the uptake of mineral nutrients and their distribution within the plants [8]. Salinity prompts heavy metals' accumulation and adversely affects nutrient contents in soil and plants, thereby reducing crop yields [9]. The study was undertaken by Alam [10] to determine the effects of varied salinity regimes on the morphological traits (plant height, number of leaves, number of flowers, fresh and dry weight) and major mineral composition of 13 selected purslane accessions. Furthermore, many nutrient interactions in salt-stressed plants can occur, which may have important consequences for growth [11]. Salinity stress affects seed germination, seedling growth, leaf size, shoot growth, shoot and root length, shoot dry weight, shoot fresh weight, number of tillers per plant, flowering stage, spikelet number, percentage of sterile florets, and productivity [12–16]. Moreover, it decreases the yield of many crops, as salt inhibits plant photosynthesis, protein synthesis, and lipid metabolism [17].

Salinity, an important abiotic stress factor limiting crop production, is increasing worldwide at an estimated rate of 1.5 million ha per year [18] and is estimated to affect 23% of cultivated lands [19]. Moreover, global annual losses in agricultural production from salt-affected land are in excess of US$ 12 billion and are rising [20]. Salinity threatens the production of abundant crops around the world [21]. Because low-quality water resources are used for irrigation, high concentrations of water are needed for crop irrigation [22].

The fact that significant areas of farmland worldwide are affected by salt has potentially serious implications for crop yield. Soil salinization is reducing the area that can be used for agriculture by 1–2% every year, with the greatest impacts in arid and semi-arid regions [23–25].

Salt tolerance is the ability of plants to grow and complete their life cycle on a substrate that contains high concentrations of soluble salt [26]. High salinity affects plants in two main ways: High concentrations of salts in the soil disrupt the capacity of roots to extract water, and high concentrations of salts within plants can be toxic, resulting in the inhibition of many physiological and biochemical processes, such as nutrient uptake and assimilation [13,27–29]. Measurements of ion contents in plants under salt stress revealed that halophytes accumulate salts, whereas glycophytes tend to exclude salts [30].

Halophytes are tolerant of high salinities (up to 200 mM NaCl). Therefore, there is increased interest in the production of new cultivars that have the potential to produce higher yields under saline conditions [31]. Halophytes, also called salt-loving plants, have the ability to withstand salinity stress and possess salt-responsive genes and proteins to counter the adverse effects of salinity [32,33].

As a result, the salinity effects the macro- and micronutrient in leaves' and soil contents, yields, and quality of a halophytic plant species (*Portulaca oleracea* L.). Therefore, we need to be able to grow salt-tolerant plants in saline soils and obtain a good harvest from them while simultaneously managing the salt contents in the soil.

2. Materials and Methods

2.1. Experimental Procedure

To conduct the experiments, a specialized greenhouse was selected at the University of Lille 1, France. The first experimental study was conducted from January–March 2016, and the second was conducted from April–June in the same year. The experiments were carried out on the halophytic plant species *Portulaca oleracea* L.

The climatic conditions of the greenhouse were monitored with an automated system at hourly intervals (every 12 min). The climatic conditions during the first experimental period were as follows: The daily air temperatures ranged from 20.1 to 24.2 °C (average, 22.2 °C), the nighttime temperatures ranged from 16.8 to 19 °C (average, 17.9 °C), the maximum relative humidity was 88.3%, and the minimum relative humidity was 12.9%. During the second experimental period (April–June 2016), the climatic conditions were as follows: The daily air temperatures ranged from 20.7 to 29.1 °C (average, 24.9 °C), the nighttime temperatures ranged from 19.3 to 22.6 °C (average, 20.9 °C), the maximum relative humidity was 90.1%, and the minimum relative humidity was 14.3%.

2.1.1. The First Experiment

Seeds of *P. oleracea* were sown in the soil on 10 January 2016. The seeds germinated on 14 January, four days after sowing, and four-leaf plants were transplanted into 3-L randomized pots (each contained 1300 g of soil) on 27 January 2016. The plants were irrigated with tap water until the beginning of the salinity treatments. The salinity treatments were as follows: T0 (1–4) (control), T1 (5–8) 50 mM NaCl, T2 (9–12) 100 mM NaCl, and T3 (13–16) 200 mM NaCl. Four plants were used per treatment. Saline treatments were performed every six days. The plants were irrigated with a minimal amount of saline water (just enough for plant survival (0.25 L/pot at the beginning of the experiment)). The salinity treatments received 0.50 L/pot of saline water until 16 February. From 21 February to 14 March, salinity treatments received 0.75 L/pot of saline water. Measurement of plant germination started one day after transplantation to the randomized pots. The stem length and the number of nodes of the plants were analyzed every five days during the vegetative period. Plants were harvested on day 50 (15 March).

2.1.2. The Second Experiment

Seeds of *P. oleracea* were directly sown into saline soil (treated just before *Portulaca oleracea* growth) on 7 April. The seeds germinated seven days after sowing (14 April 2016). Four seeds were used per treatment (T0 (1–4), T1 (5–8), T2 (9–12), and T3 (13–16)). At the beginning of the experiment, the plants were irrigated with a minimal amount of tap water (just enough for plant survival (0.25 L/pot)). As the plants developed, the water demand increased to 0.50 L/pot. Analysis of plant germination began 12 days after sowing in the randomized pots. The stem length and number of nodes were analyzed every seven days during the vegetative period. Plants were harvested on day 50 (15 June).

2.1.3. Chemical Analyses

After the end of the experimental studies, four plants from each treatment were collected, washed with distilled water for a few minutes, and wiped with paper. Then, the fresh weight (FW) of these plants was measured. The fresh samples were dried in a forced draught oven at 65 °C for 72 h before measuring their dry weight (DW), after which the plant materials were collected for chemical analyses.

Dried leaf samples were used to analyze the ion concentrations of the plants. The dry materials were ground and digested via the dry digestion method [34]. Dried leaf samples were homogenized by manual grinding in an agate mortar. The samples were precisely weighed (about 500 mg) into PTFE closed digestion cups and predigested at room temperature for 24 h using 5 mL nitric acid (65% nitric acid, Merck, Suprapur, Darmstadt, Germany) and 1 mL hydrogen peroxide (30% Merck, Suprapur) then digested on a heating block (HotBlock® SC100 Digestion System) at a temperature of 120 °C until total decomposition (~3 h). After cooling down, the solutions were then diluted to a final volume of 50 mL using ultrapure Milli-Q water (18.2 MΩ cm). The concentrations of copper (Cu^{2+}), iron (Fe^{2+}), zinc (Zn^{2+}), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), phosphorus (P), and sodium (Na^+) were determined by inductively coupled plasma-atomic emission spectrometry ICP-AES (Agilent 5110, dual view) [35]. After determination of the ion concentrations, the K^+/Na^+ and Ca^{2+}/Na^+ ratios were calculated.

Chloride ion (Cl⁻) levels were determined in an aqueous extract by titration with silver nitrate (0.01 M), according to Piper [36]. Using potassium chromate as an indicator, the volume of the sample was adapted to Cl⁻ concentration (from 10 mL to 100 mL). The plant nitrogen (N) content was determined by the Kjeldahl method [37] after conversion of organic-N to NH_3-N by digestion of 5 g of dried leaf with sulphuric acid in presence of Se catalyst, ammonia, then distilled and collected in boric acid. Analysis was completed by acid titration. All the mineral analyses were performed using soil and leaves.

3. Results

3.1. The pH and Electrical Conductivity (EC_w)

3.1.1. The pH and the EC_w of the Drainage Water

The pH and electrical conductivity (EC_w) of the drainage water were analyzed at the beginning and end of both experimental studies (from 27 January 2016 to 12 March 2016 and 27 April 2016 to 16 June 2016), after the plants were irrigated with different saline water solutions (the first exp.) or tap water (the second exp.) (Table 1). The obtained results (from the beginning and end of both experiments) showed that the pH of the drainage water slightly increased in all the treatments and that the difference in the EC_w between the first experiment and the second experiment was significant.

Table 1. The pH and electrical conductivity (EC_w) of the drainage water. Different letters within a column represent significant differences ($p \leq 0.05$).

Treatment	The First Experiment				The Second Experiment			
	27 January 2016		12 March 2016		27 April 2016		16 June 2016	
	pH	EC_w [1]	pH	EC_w	pH	EC_w	pH	EC_w
T0	5.0 ± 0.4 a	3.9 ± 0.2 a	5.6 ± 0.5 a	2.4 ± 0.1 a	6.7 ± 0.5 a	1.9 ± 0.1 a	7.0 ± 0.6 a	1.4 ± 0.0 a
T1	5.1 ± 0.4 a	4.6 ± 0.3 b	5.4 ± 0.4 a	8.5 ± 0.8 b	6.6 ± 0.5 a	7.2 ± 0.7 b	6.9 ± 0.6 a	4.5 ± 0.3 b
T2	4.9 ± 0.3 a	3.9 ± 0.2 a	5.7 ± 0.5 a	12 ± 1.3 c	6.8 ± 0.6 a	8.8 ± 0.9 b	6.8 ± 0.6 a	6.2 ± 0.6 c
T3	4.8 ± 0.2 a	5.4 ± 0.4 c	5.2 ± 0.4 ab	16 ± 2.7 d	6.1 ± 0.5 b	15.6 ± 2.5 c	6.5 ± 0.5 ab	7.8 ± 0.6 d

[1] EC_w: Electrical conductivity of the drainage water (dS m⁻¹).

First, the table shows that the electrical conductivity of the drainage water changed significantly after the salt treatment in both experiments and, by the end of the first experiment, it had tripled in the T2 and T3 treatments, doubled in the T1 treatment, and decreased 1.5 fold in the control. In the second experiment, the EC values were halved. For instance, in the T2 and T3 treatments, at the beginning of the experiment, the measures were 8.8 ± 0.9 b and 15.6 ± 2.5 c, respectively. However, at the end of the experiment, they were halved, with values of 6.2 ± 0.6 c and 7.8 ± 0.6 d, respectively.

Another noticeable trend was that the pH of the drainage water slightly increased in all the treatments. For example, the pH values in the T1 and T3 treatments were 5.1 ± 0.4 a and 4.8 ± 0.2 a, respectively. At the end of the experiment, the values in these treatments were 5.4 ± 0.4 a and 5.2 ± 0.4 ab. However, the pH values changed more in the first experiment than in the second experiment. For instance, at the beginning of the first experiment, in the T0 treatment, the pH was 5.0 ± 0.4 a, while at the end, it was 5.6 ± 0.5 a. At the beginning of the second experiment, in the T0 treatment, the pH was 6.7 ± 0.5 a, while at the end of the experiment it was 7.0 ± 0.6 a.

3.1.2. The pH and EC_s of the Soil

The results showed that the pH of the drainage water slightly increased in all the treatments, and the difference between the EC_s in the first experiment and the EC_s in the second experiment was not significant (Table 2).

Table 2. The pH and electrical conductivity (EC$_s$) of the soil. Different letters within a column represent significant differences ($p \leq 0.05$).

Treatment	The First Experiment				The Second Experiment			
	27 January 2016		12 March 2016		27 April 2016		16 June 2016	
	pH	EC$_s$ [1]	pH	EC$_s$	pH	EC$_s$	pH	EC$_s$
T0	6.6 ± 0.5 a	1.2 ± 0.1 a	6.1 ± 0.5 a	1.1 ± 0.0 a	6.2 ± 0.5 a	0.9 ± 0.0 a	6.4 ± 0.5 a	0.5 ± 0.0 a
T1	5.6 ± 0.5 a	3.0 ± 0.2 b	5.8 ± 0.5 a	3.7 ± 0.2 b	5.9 ± 0.5 a	3.3 ± 0.1 b	6.3 ± 0.5 a	1.2 ± 0.0 a
T2	4.5 ± 0.3 ab	4.6 ± 0.3 c	5.2 ± 0.4 ab	5.6 ± 0.5 c	5.8 ± 0.5 a	4.4 ± 0.3 ab	6.3 ± 0.5 a	2.0 ± 0.1 ab
T3	4.3 ± 0.3 ab	6.2 ± 0.5 d	5.0 ± 0.4 ab	9.0 ± 0.8 d	5.6 ± 0.5 ab	8.1 ± 2.8 c	6.0 ± 0.4 a	3.2 ± 0.2 ab

[1] EC$_s$: Electrical conductivity of the extract of a saturated soil paste (dS m^{-1}).

Specifically, the table shows that the electrical conductivity (EC$_s$) of the soil did not change significantly after the soil treatment in either experiment. For instance, in the first experiment, in the T0 and T1 treatments, the EC$_s$ values were 1.2 ± 0.1 a and 3.0 ± 0.2 b, respectively. At the end of the experiment, the values were 1.1 ± 0.0 a and 3.7 ± 0.2 b. Furthermore, in the T3 treatment, there were significant changes in the electrical conductivity (EC$_s$) between the beginning and the end of the first experiment. At the beginning of the experiment, the EC$_s$ was 6.2 ± 0.5 d, but at the end, it was 9.0 ± 0.8 d.

Another noticeable trend is that the pH of the soil slightly increased in all the treatments. For example, the pH values in the T1 and T3 treatments were 5.6 ± 0.5 a and 4.3 ± 0.3 ab, respectively, at the beginning of the experiment, while at the end of the first experiment, the values were 5.8 ± 0.5 a and 5.0 ± 0.4 ab.

3.2. Fresh and Dry Weights of the Plants

The changes in fresh weight (FW) related to the roots and shoots of *P. oleracea* under salinity stress are presented in Figure 1a. The lowest values of stem, leaf, and seed FW were found in the T3 treatment; the other salinity treatments (T1 and T2) had no effect on the leaf and seed FW of the plants. However, with NaCl concentrations greater than 200 mM, the crop FW decreased by approximately 33.6% compared to the control treatment. The increases in the ratio of stem and leaf FWs in the salinity treatments (T1 and T2) were significant compared to those in the control treatment. The plants produced low amounts of dry matter, which ranged from 1.5 to 0.53 g plant^{-1} (Figure 1b). There was an increase in the percentage of dry matter from the stems and leaves of the plants grown under saline conditions and a decrease in seed dry matter with the increase in salinity (100–200 mM NaCl).

The plants were grown under the same conditions as those used in a previous experiment (i.e., the treatments were applied just before *P. oleracea* was grown in saline soil) (Figure 1c). The leaf FW in the control treatment (T0; 5.4 g plant^{-1}) decreased more than the leaf FW in the T1 (12.5 g plant^{-1}), T2 (15.9 g plant^{-1}), and T3 (19.7 g plant^{-1}) treatments, and the fresh weight of the stem in the T0 (10.8 g plant^{-1}) treatment was lower than the fresh weight of the stem in the T1 (18.5 g plant^{-1}), T2 (21.7 g plant^{-1}), and T3 (19.7 g plant^{-1}) treatments with saline soil.

The dry weight of *P. oleracea* decreased significantly in the control group compared to that in the salinity treatments (T1, T2, and T3) (Figure 1d). Indeed, the dry weight of the control group was 2.27 fold lower than that of all the salinity treatments.
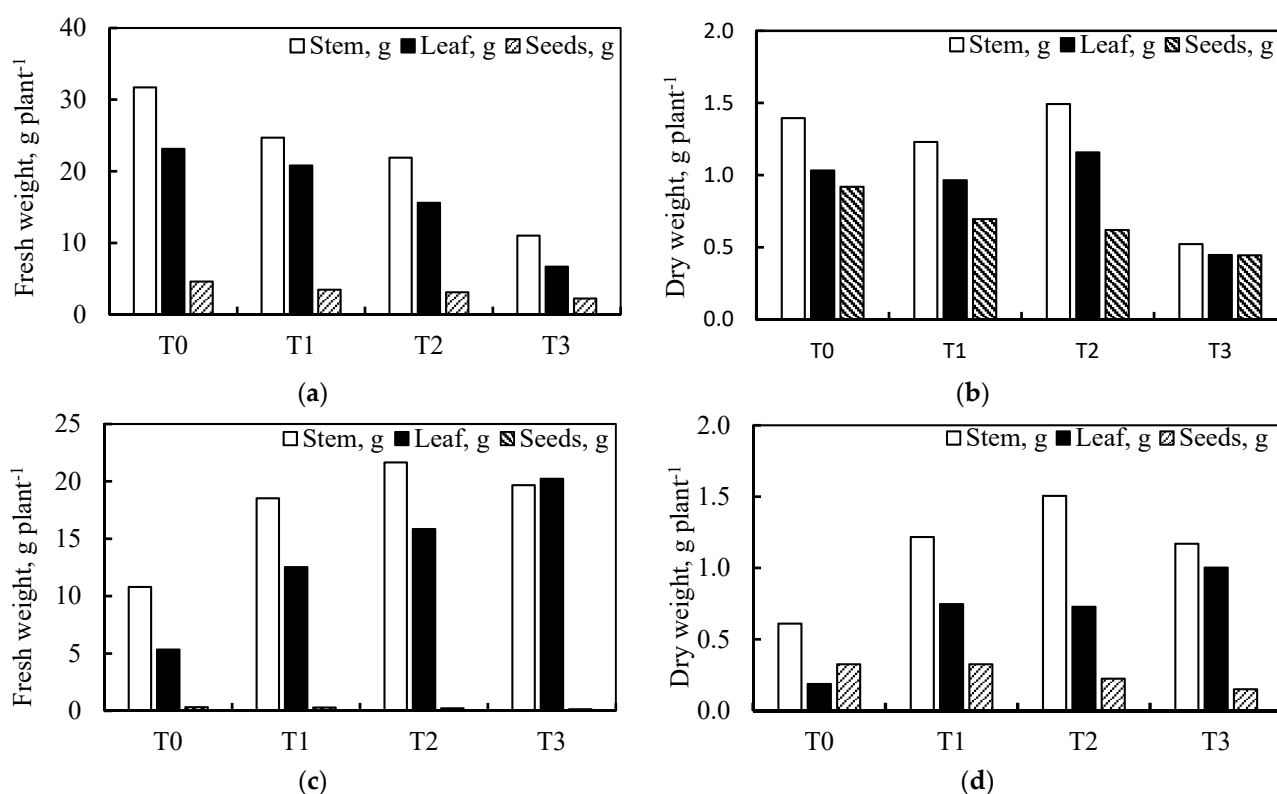
Figure 1. Fresh and dry weight of crops (**a**,**b** first experiment; **c**,**d** second experiment).

3.3. Root Length of P. oleracea

The root length of the plants in the first experimental study showed low variation among the treatments (Table 3). There was a decrease in the root length of the plants in the high-salinity treatment (T3). Compared to that in the T1, T2, and control (T0) treatments, an approximately 1.4-fold decrease in the ratio of the root length of the plants was observed in the T3 treatment compared to the T1, T2, and control (T0) treatment.

Table 3. Root length of *P. oleracea* species. Different letters within a column represent significant differences ($p \leq 0.05$).

Treatment	Root Length, cm	
	The First Exp.	**The Second Exp.**
T0	25.0 ± 4.88 a	25.7 ± 1.26 a
T1	25.5 ± 3.18 a	19.7 ± 2.47 ab
T2	25.0 ± 1.73 a	20.3 ± 1.82 ab
T3	18.5 ± 1.32 ab	18.5 ± 2.04 ab

Salinity (NaCl) had a significant effect on the root length of the plants in treatments T1 (19.7 cm), T2 (20.3 cm), and T3 (18.5 cm) in the second experiment. There was low variation among the salinity treatments and a significant difference the control treatment (T0). The root length results showed that the saline soils may have had a major impact in the early stages of plant seed germination.

3.4. Macro- and Micronutrient Content in Leaves

In this study, salinity stress affected micronutrient and macronutrient uptake by leaves (Figure 2a,b). The analysis revealed a significant difference between salinity levels in terms of macronutrient accumulation in the plants. The salinity levels significantly affected all the macronutrients in the leaves. The salinity levels caused significant changes

in the performance of the plants in all the treatments. The plants in all the treatments showed increased potassium (K^+) content in their leaves. A slightly significant result was observed for the calcium content (Ca^{2+}). Moreover, calcium (Ca^{2+}) accumulation increased in the salinity treatments. Interestingly, the levels of the macronutrients phosphorus (P), magnesium (Mg^{2+}), and sulphur (S) in the leaves were constant among all the treatments.
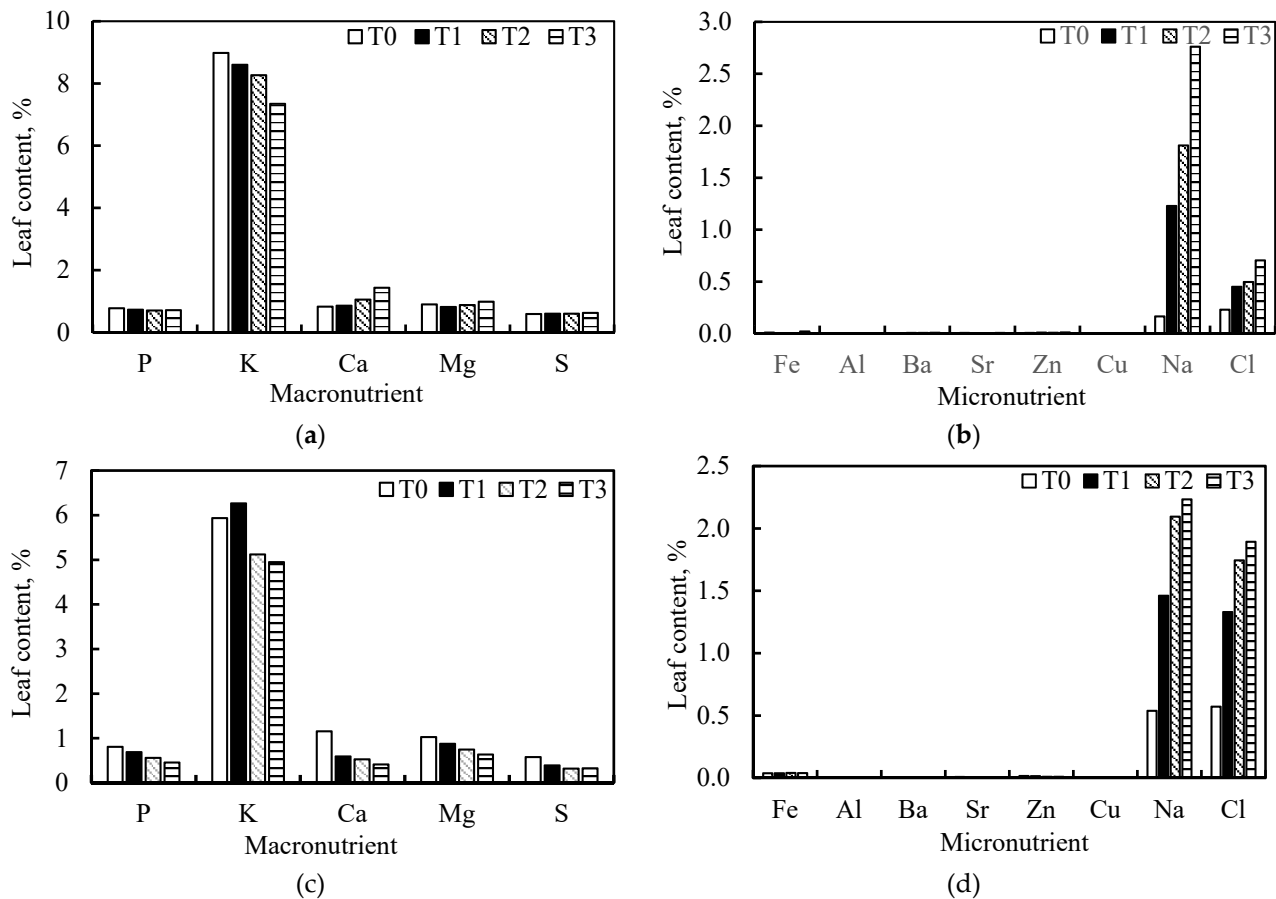

Figure 2. Macronutriment and micronutrient levels in leaves (**a**,**b** first experiment; **c**,**d** second experiment).

The salinity levels significantly affected the Na^+ and Cl^- contents in all the treatments, but there were significant differences among the treatments. There was an increase in the sodium content in the leaves of *P. oleracea* at high-salt concentrations. Among the treatments, the highest Na^+ accumulation (2.76%) occurred in the treatment with the highest salinity level (T3). At this high-salinity level, the leaf chloride (Cl^-) content was significantly lower than the Na^+ content. The contents of the micronutrients Fe, Al, Ba, Sr, Zn, and Cu in the leaves were very low in all the treatments (Figure 2b).

P. oleracea was found to be a crop with high potential for salt (ion) removal. High levels of Na^+ and Cl^- in the soil increased the levels of the macronutrient potassium (K^+) in the leaves in all the treatments (Figure 2c). The results indicated that the levels of the macronutrients phosphorus (P), calcium (Ca^{2+}), magnesium (Mg^{2+}), and sulphur (S) in the leaves decreased in all the saline soil treatments compared to the control group.

The levels of the micronutrients Fe, Al, Ba, Sr, Zn, and Cu were very low in all treatments. The sodium (Na^+) content in the leaves increased significantly with increasing salinity levels in the saline soils. There was an increase in the chloride (Cl^-) content in the leaves of the plants in the treatments with high-salt concentrations (T1, T2, T3) compared to that in the control group (Figure 2d).

3.5. Macro- and Micronutrients in the Soil

The high-salinity treatments significantly affected the macro- and micronutrients in the soil. The low concentrations of the macronutrients N, P, and K showed no variation between the soil treatments (Figure 3a).
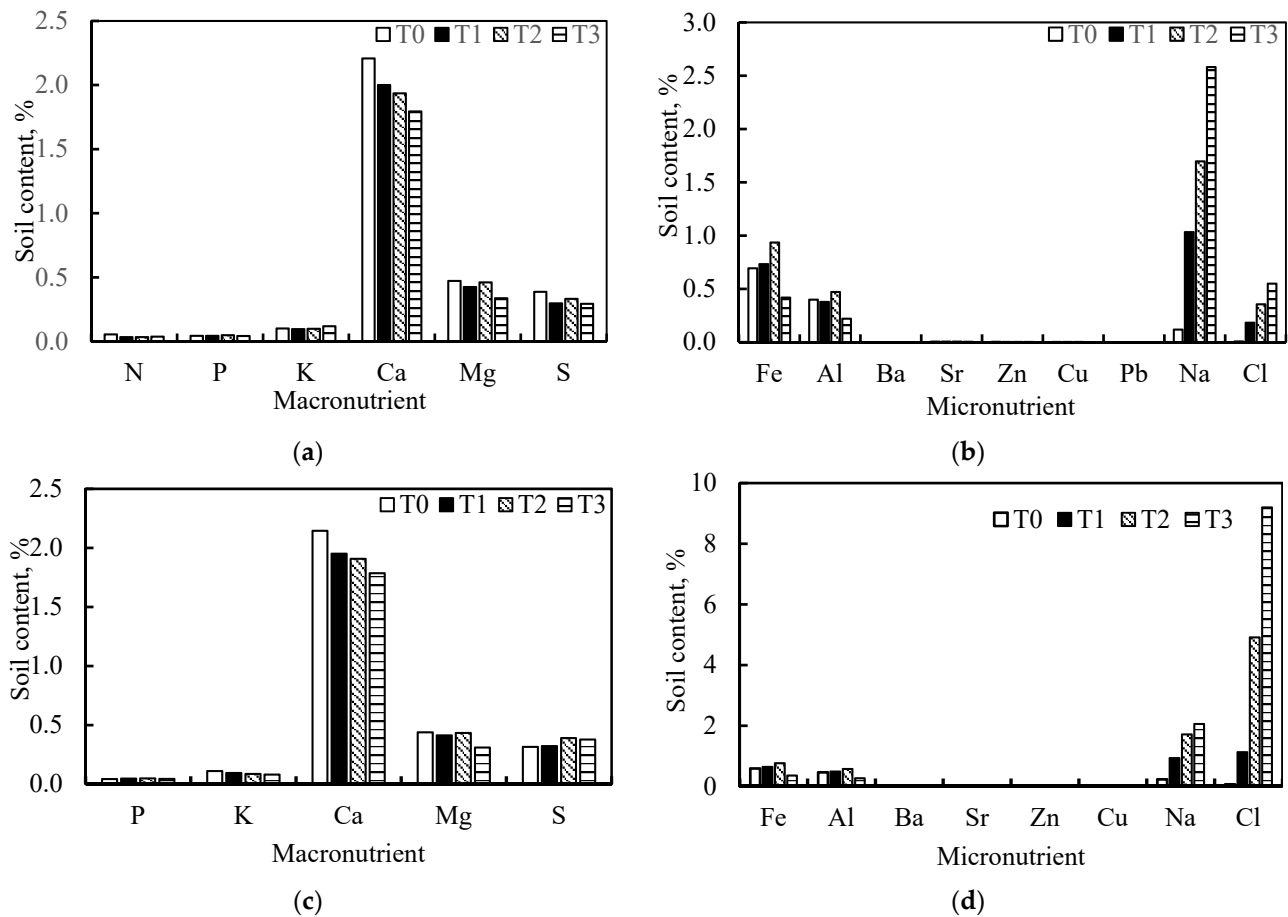

Figure 3. Macronutriment and micronutrient levels in soil (**a**,**b** first experiment; **c**,**d** second experiment).

The levels of the macronutrients iron (Fe) and aluminum (Al) in the soil increased slightly in a salinity treatment (T2) compared to the T0 treatment (Figure 3b). There was low variation in the soil aluminum (Al) content among the treatments. The soil Ba, Sr, Zn, Cu, and Pb levels were very low in all the treatments. The salinity levels in the irrigation water had a significant effect on the soil sodium (Na^+) content. There was an increase in the sodium (Na^+) content in the soil when the salinity concentration was high. There was variation in all the treatments. The soil chloride (Cl^-) content showed low variation among the salinity treatments.

The levels of essential elements (P and K) in the soil were very low, and there was no variation among the treatments. Soil salinity had a significant effect on the level of macronutrients (e.g., Ca^{2+}), although the soil Mg^{2+} and S levels were not significantly affected (Figure 3c).

The concentrations of the micronutrients Fe and Al were low in the soil in all the salinity treatments. Salinity stress had no effect on the micronutrients Ba, Sr, Zn, Cu, and Cu^{2+} in the soil. The soil sodium (Na) content was significantly increased in the high-salinity treatments compared to the control group. There was a large increase in the soil chloride (Cl) content in all the salinity treatments, namely, T1 (1.13%), T2 (4.9%), and T3 (9.2%) (Figure 3d).

3.6. Macro- and Micronutrient Levels in Drainage Water

Plants that are irrigated with a large amount of water may suffer from the loss of mineral contents (macro- and micronutrients) in the soil. On the other hand, they may benefit from the removal of salts from the soil.

The drainage water from each irrigation event was analyzed during the experiment study. Macro- and micronutrient analysis of the drainage water was performed with ICP-AES in a laboratory. The obtained results show that the concentrations of the macronutrients calcium (Ca^{2+}) and sulphur (S) in the drainage water increased from 150 mg/L to 260 mg/L. The phosphorus (P), potassium (K^+), and magnesium (Mg^{2+}) levels in the drainage water decreased in all the treatments (Figure 4a).
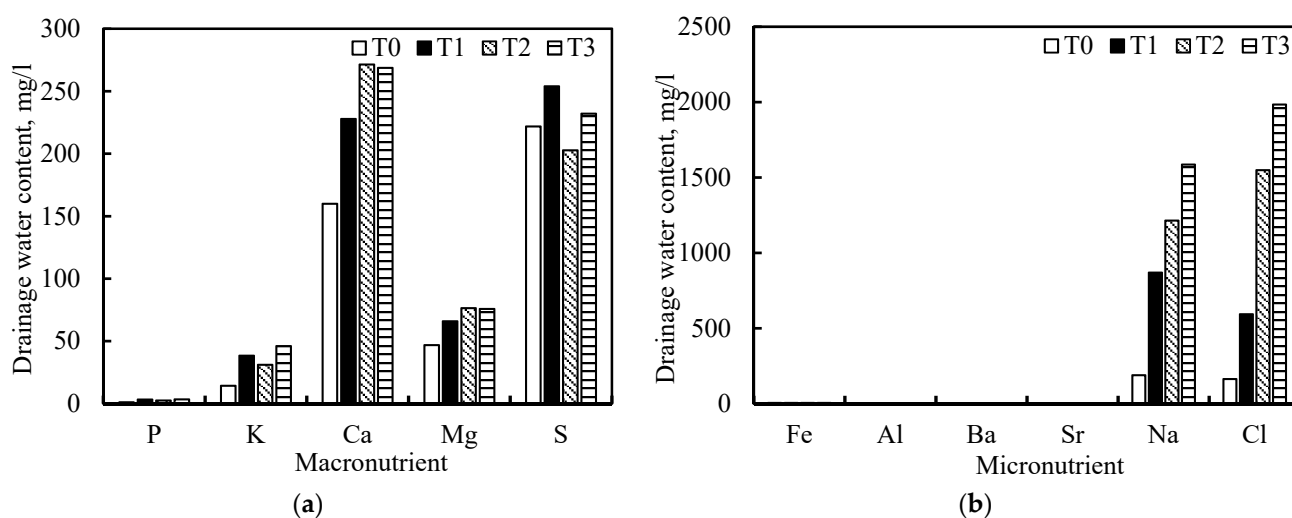

Figure 4. Macronutriment (**a**) and micronutrient (**b**) levels in the drainage water.

The drainage water removed large amounts of the micronutrients sodium (Na^+) and chloride (Cl^-) from the soil during the final irrigation event. The Na^+ content in the drainage water was higher in treatments T1 (870 mg/L), T2 (1214 mg/L), and T3 (1586 mg/L) than in the control (T0; 189 mg/L). The Cl^- content in the drainage water increased more in treatments T1 (593 mg/L), T2 (1549 mg/L), and T3 (1984 mg/L) than in the control (T0; 163 mg/L). These results confirmed that the irrigation water removed a large amount of macro- and micronutrients from the soil (Figure 4b).

3.7. Yields of P. oleracea

Several salinity (NaCl) levels affected the yield of *P. oleracea*. The values of the total fresh weight (FW) and dry weight (DW) of *P. oleracea* were significantly different among treatments (Table 4). The highest yield (3.25 DW g plant^{-1}) (53.25 FW g plant^{-1}) was observed in the control treatment (T0).

Table 4. Yield of *P. oleracea* (in the first experiment). Different letters within a column represent significant differences ($p \leq 0.05$).

Treatment	*Portulaca oleracea*		
	FW (g plant^{-1})	**DW (g plant^{-1})**	**Yield (%)**
T0	59.25 ± 6.1 a	3.25 ± 0.48 a	5.5 ± 0.28 ab
T1	49.0 ± 9.7 a	2.75 ± 0.75 ab	5.5 ± 0.28 ab
T2	40.75 ± 5.2 ab	3.25 ± 1.03 a	7.25 ± 1.60 a
T3	20.0 ± 2.7 b	1.5 ± 0.29 b	7.0 ± 0.41 a

Significant high variation in fresh weight was observed among the treatments (Table 5). The highest fresh weight (40.1 g) was recorded in the high-salinity soil in treatment T3, and

the lowest (16.5 g) was found in the control treatment. These results show that soil salinity has an effect on the yield of *Portulaca oleracea*. The maximum grain yield was measured in treatment T3, with an average of 40.25 FW g plant^{-1}, and the minimum yield was obtained in the T0 treatment (16.5 FW g plant^{-1}). Despite the effect of soil salinity, the yield of *P. oleracea* in treatments T1, T2, and T3 increased (1.9–2.4-fold increase in fresh weight and 2–2.2-fold increase in dry weight) in comparison to that in the control treatment. The analysis of the plant yield confirmed that *P. oleracea* is halophytic.

Table 5. Yield of P. oleracea (in the second experiment). Different letters within a column represent significant differences ($p \leq 0.05$).

Treatment	*Portulaca oleracea*		
	FW (g plant^{-1})	DW (g plant^{-1})	Yield (%)
T0	16.5 ± 2.99 b	1.0 ± 0.41 ab	6.5 ± 0.65 ab
T1	31.75 ± 4.23 ab	2.3 ± 0.48 a	7.0 ± 1.08 a
T2	37.5 ± 11.55 ab	2.3 ± 0.75 a	6.5 ± 0.29 ab
T3	40.25 ± 4.99 a	2.5 ± 0.64 a	5.75 ± 0.85 b

4. Discussion

The values of all the variables decreased in the second experiment relative to the values observed in the first experiment. In the second irrigation event, we observed that the electrical conductivity of the drainage water (EC$_w$) increased relative to that in the first irrigation event, then decreased steadily with further irrigation events. This can be attributed, first, to the assimilation of salts in the soil by salt-tolerant plants [38–42] and, second, to the process of salt leaching from the soil by irrigation [43,44].

Growth retardation and the loss of fresh and dry weights from stems and leaves of plants under salinity stress have been observed in previous studies [45–47]. In addition, based on fresh and dry weights, it has been demonstrated in several studies that the shoot ratios of many plants increase under salinity stress [44,48,49].

P. oleracea was demonstrated to be tolerant to salinity stress. This characteristic has already been studied in several crops, where development was adversely affected, with a significant decrease in production due to a shallow GWT [50,51].

The effects of salinity stress on microelement uptake have been investigated in various studies [52,53]. However, the relationship between salinity and microelement uptake is complex. An increase or decrease may be observed in microelement uptake, or salinity may not have an effect on the microelement concentration of the plant. These differences result from factors such as plant species, plant tissues, level of salinity stress and composition, microelement concentration in the growth medium, growth conditions, and stress duration [54]. Eom et al. [55] suggested that salinity stress does not affect Fe^{2+} or Zn^{2+} uptake in six different types of ground cover plants but reduces the concentration of Cu^{2+}.

There was an increase in the soil calcium (Ca^{2+}) content in all the treatments. However, non-saline soil was found to have the same amount of Ca as the control group [56]. Magnesium (Mg^{2+}) and sulphur (S) showed low variation between the treatments.

A similar result was obtained by Vural [57], with the yield of cultivated purslane ranging between 30 t ha^{-1} and 50 t ha^{-1}. In addition, the yield of cultivated purslane was affected by seed quality, planting time, growing conditions, and plant care practices [57]. For example, Ehni et al. [58] reported that the yield of purslane varied by year and variety, and the highest yields were obtained for *Portulaca sativa* (70,003 kg ha^{-1}) and *Egyptian* (37,130 kg ha^{-1}). The lowest yield value (approximately 353.7 DM kg ha^{-1}) was obtained in the treatment with the highest salinity concentration in the irrigation water (treatment T3). However, the total dry weight was significantly reduced in treatments with higher salinity levels (5–20 dS m^{-1}), suggesting that the effects of salt toxicity manifested as growth repression. Plant growth started during the day on 17 December and 20 January, upon applying saline water. The application of NaCl at a concentration of 20 dS m^{-1} led to

a significant reduction in the dry weight of the plants (by 42.3%) compared to that in the control group. These results were confirmed by previous research conducted by Hamidov [59,60].

5. Conclusions

The results of the first experiment suggested that the cultivated species showed an increase in growth characteristics, such as yield, with the application of different salinity treatments. *P. oleracea* was relatively tolerant to saline conditions. The plant salt extraction analysis showed that the tissues of *P. oleracea* accumulated the largest amounts of sodium in the study. In the current study, salt concentrations higher than 100 mM NaCl significantly increased the dry weights of the whole plant (total biomass), while high salt levels (200 mM NaCl) significantly decreased the dry weight (DW) ratio. Therefore, salinity stress was determined to have a significant impact on micronutrient and macronutrient uptake. Despite the increasing salinity stress, an increase in the soil Ca^{2+} content led to an increase in the tolerance of *P. oleracea* to stress. Under saline conditions, the uptake of Ca^{2+}, K^+, and Na^+ by *P. oleracea* was an important indicator of the effects of stress.

Soil salinity and water salinity are directly related to plant growth stress and decreasing yield. Considering this global problem, in this study, we tested the biomass yield loss and physiological characteristics of an agronomic species under soil salinity stress. The results revealed that, although there was significant variation in the measured parameters among all the treatments, *P. oleracea* is generally a highly salt-tolerant crop plant capable of producing a satisfactory amount of dry matter content, which is a desirable characteristic for any salt-tolerant plant species. In conclusion, our results indicated that *P. oleracea* is able to grow in high-salinity soil. This finding was confirmed by the dry matter obtained under high-salinity conditions.

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