The impact of different Zinc (Zn) levels on growth and nutrient uptake of Basil (*Ocimum basilicum* L.) grown under salinity stress

**Inci Tolay**

Department of Soil Science and Plant Nutrition, Akdeniz University, Faculty of Agriculture, Antalya, Turkey

* incitolay@akdeniz.edu.tr

**Abstract**

Salinity is among the most important abiotic stresses, which negatively affect growth, nutrient uptake and yield of crop plants. Application of different micronutrients, particularly zinc (Zn) have the potential to ameliorate the negative impacts of salinity stress. However, the role of Zn in improving salinity tolerance of basil (*Ocimum basilicum* L.) is poorly understood. This study evaluated the impact of different Zn levels (0, 5 and 10 mg kg\(^{-1}\)) on growth and nutrient acquisition traits of basil under different salinity levels (0, 0.5, 1.0 and 1.5% NaCl). Data relating to biomass production, chlorophyll index, sodium (Na), potassium (K) uptake, K/Na ratio, Zn, copper (Cu), manganese (Mn) and iron (Fe) uptake were recorded. Increasing salinity level reduced biomass production, chlorophyll index and nutrient uptake traits (except for Na and Fe accumulation) of basil. Zinc application (10 mg kg\(^{-1}\)) improved biomass production, chlorophyll index and nutrient acquisition traits under normal as well as saline conditions. The reduction in chlorophyll index and biomass production was higher under 0 and 5 mg kg\(^{-1}\) than 10 mg kg\(^{-1}\) Zn application. The K concentration decreased under increasing salinity; however, Zn application improved K uptake under normal as well as saline conditions. Different growth and nutrient acquisition traits had negative correlations with Na accumulation; however, no positive correlation was recorded among growth and nutrient uptake traits. The results revealed that Zn application could improve the salinity tolerance of basil. However, actual biochemical and genetic mechanisms involved in Zn-induced salinity tolerance warrant further investigation.

**Introduction**

Salinity is an important constraint for crop production in many geographic regions of the world, and frequently occurs in irrigated lands of arid and semi-arid regions [1]. Irrigation water containing trace amounts of sodium chloride (NaCl) increases salt levels in arable soils [2, 3]. Globally, salinity affects 831 million hectares of land [4], and the saline area is increasing with each passing day [5]. Salinity excludes 1.5 million hectares of productive lands from agricultural production each year [3]. Salinity is of important concern for salt sensitive crops grown in arid zones [6, 7]. Soil and water salinity are major constraints in global food
production, particularly in semi-arid and arid regions [8]. Saline groundwater is commonly used to fulfill moisture requirements of crops sown in areas with limited water resources [9–12]. Nonetheless, recycling of wastewater and its use for irrigation are also gaining popularity [13, 14].

Salinity is among the most important abiotic stresses, which limit plant production; thus, studied for many years. Salinity can directly damage plants, or inhibit plant growth depending on salinity-tolerance level of plants and salt concentration in the environment [3, 14]. Salinity induces chlorophyll and membrane breakdown (chlorosis and necrosis) starting from old leaves [15, 16]. Salinity causes toxicity and mineral nutritional disorders in plants, ultimately resulting in disturbed metabolism [15]. Thus, salinity causes both qualitative and qualitative yield losses by limiting plant growth [17]. The growth-limiting factors for plant growing under saline environments can be categorized in 3 different groups [15], which are water stress, Na\(^+\) and Cl\(^-\) toxicity and associated nutrient uptake, ion toxicities and deficiency of K\(^+\) and Ca\(^{++}\).

Reclamation of saline soils through leaching soil profile is frequently recommended in the literature to eliminate negative consequences on plant growth [18, 19]. However, this approach is time-consuming and costly. In addition, salinity mostly occurs in arid and semi-arid regions where water-based solutions are not practical. While salinity is a common problem of arid and semi-arid regions, zinc (Zn) deficiency also impairs plant production in the same regions. Although yield and quality of plants are negatively affected by salinity around the world [17, 20], Zn deficiency often occurs in calcareous, saline and sodic soils with high pH values [21, 22]. In addition to adverse impacts of Zn deficiency on yield and quality of plants, it is also a serious problem for human nutrition.

Zinc reduces excessive Na uptake under saline environments through affecting structural integrity and permeability of stem cell membrane [23]. Zinc nutrition is effective in decreasing Na accumulation and improving K/Na ratio in plants under salinity [1, 24]. Therefore, cell membranes show high permeability or leakage of some compounds from the roots under Zn deficiency [25]. Zinc deficiency can lead to accumulation of toxic ions such as Na and Cl. Therefore, combined effects of salinity and Zn-deficiency on plant growth are important and need investigation.

Basil (Ocimum basilicum L.), a member of Lamiaceae is an annual, herbaceous plant of Mediterranean regions. The basil is rich in antioxidant and phenolic compounds, such as rosmarinic acid and other caffeic acid derivatives, and is regarded as a source of aromatic compounds [26]. The plant is grown as a medicinal and spice plant in many countries of the world [27, 28]. The large consumption of basil as a food ingredient makes it a possible candidate of bio-fortification.

Although impacts of salinity and Zn have been investigated on many plants, there are almost no studies carried out on basil. Therefore, this study determined the growth, biomass production and nutrient uptake response of basil under different salinity and Zn application levels. It was hypothesized that increasing salinity level will suppress the growth and nutrient uptake, whereas increasing Zn levels will ameliorate the negative consequences of salinity on basil.

**Materials and methods**

**Experimental site**

The study was conducted on basil population grown in Aegean Region. A calcareous and Zn-deficient soil having DTPA extractable Zn level of 0.20 mg kg\(^{-1}\) was used in the study. The pH of the experimental soil and total salts were analyzed following Jackson [29]. The method of Bouyoucos [30] was followed to determine soil texture. Organic matter was analyzed...
according to Walkley and Black [31]. Total phosphorus (P) and potassium (K) were analyzed by following Olsen [32] and Carson [33], respectively. Iron (Fe), zinc (Zn), manganese (Mn) and copper (Cu) were analyzed according to Lindsay and Norvell [34]. The experimental soil was slightly alkaline (pH 8.02), non-saline (0.24 mmhos cm⁻¹), clay-loam, low in organic matter (1.1%), moderately calcareous (10.2%), low in available P (4.8 mg kg⁻¹), sufficient in available K (149 mg kg⁻¹), Zn-deficit (0.2 mg kg⁻¹), medium in Fe (0.85 mg kg⁻¹), low in Mn (2.74 mg kg⁻¹) and sufficient in Cu content (0.46 mg kg⁻¹).

**Experimental treatments**

Four salinity levels (i.e., 0, 0.5, 1 and 1.5% NaCl) were used in the experiment. Similarly, three Zn application levels [i.e., Zn₀ = 0 mg kg⁻¹, Zn₅ = 5 mg kg⁻¹ and Zn₁₀ = 10 mg kg⁻¹ Zn (in the form of Zn SO₄·7H₂O)] were included in the study. All treatments had three replications. The experiments were performed in greenhouse of Çukurova University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition. Basic nutrients, i.e., 200 mg kg⁻¹ N in the form NH₄SO₄, 100 mg kg⁻¹ P and 125 mg kg⁻¹ K in the form of KH₂PO₄ and 2.5 mg kg⁻¹ Fe in the form of Fe-EDTA were applied. The pots were filled with 1.65 kg of soil and 20 seeds were planted in each pot. After seed germination, plants were reduced to 10 per pot. Salinity was imposed through irrigation water three times with an interval of two days [35] and 0, 0.5, 1 and 1.5% (w/v) NaCl solutions were applied 53 days after planting. The pots of salinity-free treatment were maintained at field capacity by irrigating with distilled water. Experiments were conducted according to factorial design where salinity was considered as main factor, while Zn application levels were regarded as sub-factor. There were no specific permits required for the experiments since no endangered/protected species were involved in the study.

**Data collection**

The SPAD values were determined at the end of experiment. Aboveground parts were harvested on the 72nd day depending on Zn deficiency symptoms observed in control treatment. The harvested plants were dried at 65°C for 48 hours to determine biomass production. The dried plants were weighed and a pre-weighed quantity was burnt in H₂O₂-HNO₃ acid mixture in a closed system (Milestone 1200 Mega) microwave oven for Zn analysis. The Zn, K and Na concentrations in the obtained filtrate were measured in an Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) device.

**Statistical analysis**

The collected data were tested for normality and homogeneity of variance first, which indicated a normal distribution. Two-way analysis of variance (ANOVA) was used to infer significance in the data. Least significant difference test at 5% probability level was used as a post-hoc test to separate the means. All statistical analyses were performed on SPSS version 20.0.

**Results**

Salinity and zinc (Zn) levels and their interaction significantly altered biomass production and chlorophyll index (Table 1).

Plants grown under salinity-free environment produced the highest biomass, whereas those grown under 1.5% salinity level produced the lowest biomass (Fig 1). Similarly, the lowest biomass production was recorded for the plants grown under no Zn application, whereas plants grown under Zn₅ and Zn₁₀ levels produced the highest biomass (Fig 2). Regarding interaction
among salinity and Zn levels, plants grown under 1% salinity and no Zn treatment had the lowest biomass production, whereas no salinity with Zn5 and Zn10 treatments resulted in the highest biomass production (Fig 3).

The lowest chlorophyll index was noted for the plants grown under 1.5% salinity, whereas plants grown under no salinity had the highest chlorophyll index (Fig 4). Similarly, the lowest and the highest chlorophyll index was recorded for the plants grown under Zn0, Zn5 and Zn10 levels, respectively (Fig 5). Regarding interaction of salinity × Zn levels, plants grown under

---

Table 1. Analysis of variance for biomass production, chlorophyll index, nutrient acquisition traits and K/Na ratio of Basil (Ocimum basilicum L.) grown under different NaCl salinity and zinc (Zn) levels.

| Source          | DF | Sum of squares | Mean squares | F value | P value   |
|-----------------|----|---------------|--------------|---------|-----------|
| **Biomass production** |     |               |              |         |           |
| Salinity levels (S) | 3  | 0.04          | 0.01         | 86.91   | < 0.0001* |
| Zn levels (Zn)     | 2  | 0.01          | 0.01         | 43.93   | < 0.0001* |
| S × Zn             | 6  | 0.01          | 0.00         | 6.28    | 0.0005*   |
| **Chlorophyl index** |    |               |              |         |           |
| Salinity levels (S) | 3  | 2545.04       | 848.35       | 233.87  | < 0.0001* |
| Zn levels (Zn)     | 2  | 389.98        | 194.99       | 53.75   | < 0.0001* |
| S × Zn             | 6  | 332.56        | 55.43        | 15.28   | < 0.0001* |
| **Na accumulation** |      |               |              |         |           |
| Salinity levels (S) | 3  | 192.13        | 64.04        | 1822.43 | < 0.0001* |
| Zn levels (Zn)     | 2  | 3.81          | 1.91         | 54.27   | < 0.0001* |
| S × Zn             | 6  | 17.23         | 2.87         | 81.71   | < 0.0001* |
| **K accumulation**  |     |               |              |         |           |
| Salinity levels (S) | 3  | 15.00         | 5.00         | 108.44  | < 0.0001* |
| Zn levels (Zn)     | 2  | 0.57          | 0.28         | 6.15    | 0.0070**  |
| S × Zn             | 6  | 0.57          | 0.09         | 2.04    | 0.0988**  |
| **K/Na ratio**      |     |               |              |         |           |
| Salinity levels (S) | 3  | 24.59         | 8.20         | 617.74  | < 0.0001* |
| Zn levels (Zn)     | 2  | 1.64          | 0.82         | 61.77   | < 0.0001* |
| S × Zn             | 6  | 2.10          | 0.35         | 26.39   | < 0.0001* |
| **Zn accumulation** |     |               |              |         |           |
| Salinity levels (S) | 3  | 92.92         | 30.97        | 4.27    | 0.001*    |
| Zn levels (Zn)     | 2  | 19529.54      | 9764.77      | 1346.40 | < 0.0001* |
| S × Zn             | 6  | 462.95        | 77.16        | 10.64   | < 0.0001* |
| **Cu accumulation** |     |               |              |         |           |
| Salinity levels (S) | 3  | 2.08          | 0.69         | 4.83    | 0.0090*   |
| Zn levels (Zn)     | 2  | 9.77          | 4.88         | 34.08   | < 0.0001* |
| S × Zn             | 6  | 11.01         | 1.83         | 12.80   | < 0.0001* |
| **Mn accumulation** |      |               |              |         |           |
| Salinity levels (S) | 3  | 4820.70       | 1606.90      | 75.74   | < 0.0001* |
| Zn levels (Zn)     | 2  | 1197.66       | 598.83       | 28.23   | < 0.0001* |
| S × Zn             | 6  | 1764.52       | 294.09       | 13.86   | < 0.0001* |
| **Fe accumulation** |      |               |              |         |           |
| Salinity levels (S) | 3  | 68544.94      | 22848.31     | 547.18  | < 0.0001* |
| Zn levels (Zn)     | 2  | 9818.04       | 4909.02      | 117.56  | < 0.0001* |
| S × Zn             | 6  | 45133.57      | 7522.26      | 180.15  | < 0.0001* |

DF = degree of freedom

* = significant, NS = non-significant

https://doi.org/10.1371/journal.pone.0246493.t001
1.5% salinity and Zn5 had the lowest chlorophyll index, whereas no salinity with Zn5 resulted in the highest chlorophyll index (Fig 6).

Individual and interactive effects of salinity and Zn levels significantly affected different nutrient acquisition traits such as sodium (Na), potassium (K), K/Na ratio, Zn, copper (Cu), manganese (Mn) and iron (Fe) uptake (Table 1). The highest and the lowest Na accumulation was recorded for plants grown under 1.5 and 0% salinity, respectively. Similarly, plants grown under Zn5 acquired the highest amount of Na, whereas 10 mg kg$^{-1}$ Zn resulted in the lowest Na accumulation. Nonetheless, plants grown under no salinity and 10 mg kg$^{-1}$ Zn accumulated...
the lowest amount of Na, whereas 1.5% salinity and 5 mg kg\(^{-1}\) Zn resulted in the highest Na accumulation (Table 2).

Plants grown under 0% salinity accumulated the highest amount of K, whereas plants form rest of the salinity levels accumulated similar amounts of K. Similarly, plants grown under Zn\(_5\) level acquired the highest amount of K, whereas Zn\(_0\) application resulted in the lowest K accumulation. In the same way, plants grown under 0% salinity with Zn\(_{10}\) acquired the highest amount of K, while similar amounts of K accumulated in the rest of interactions (Table 2).

Fig 3. The influence of different zinc levels on dry biomass production of Basil (\textit{Ocimum basilicum} L.) grown under different NaCl salinity levels. The vertical bars are means ± standard errors. Any two means having different letters are statistically different from each other (p < 0.05).

https://doi.org/10.1371/journal.pone.0246493.g003

Fig 4. The influence of different NaCl salinity levels on chlorophyll index of Basil (\textit{Ocimum basilicum} L.). The vertical bars are means ± standard errors. Any two means having different letters are statistically different from each other (p < 0.05).

https://doi.org/10.1371/journal.pone.0246493.g004
The highest K/Na ratio was recorded under 0% salinity and Zn\textsuperscript{10} level. However, the lowest K/Na ratio was observed in 1 and 1.5% salinity levels and Zn\textsuperscript{5} and Zn\textsuperscript{10} levels. Regarding interactive effect, 0% salinity with Zn\textsuperscript{10} level had the highest K/Na ratio, whereas 1 and 1.5% salinity levels with all Zn application levels had the lowest K/Na ratio (Table 2).

The highest Zn uptake was noted for the plants grown under 0.5% salinity and Zn\textsuperscript{10} application, whereas Zn\textsuperscript{0} application and 1% salinity resulted in the lowest Zn accumulation. Regarding the interaction of salinity $\times$ Zn application levels, 0.5% salinity with Zn\textsuperscript{10} recorded the

![Figure 5](https://doi.org/10.1371/journal.pone.0246493.g005)

**Fig 5.** The influence of different Zinc (Zn) levels on chlorophyll index of Basil (*Ocimum basilicum* L.). The vertical bars are means $\pm$ standard errors. Any two means having different letters are statistically different from each other ($p < 0.05$).

![Figure 6](https://doi.org/10.1371/journal.pone.0246493.g006)

**Fig 6.** The influence of different Zinc (Zn) levels on chlorophyll index of Basil (*Ocimum basilicum* L.) grown under different NaCl salinity levels. The vertical bars are means $\pm$ standard errors. Any two means having different letters are statistically different from each other ($p < 0.05$).
highest Zn accrual, while no salinity with no Zn application had the lowest Zn accumulation (Table 2).

Plants grown under 0.5% salinity and Zn\textsubscript{10} application resulted in the highest Cu uptake, whereas Zn\textsubscript{0} application and 1% salinity resulted in the lowest Cu accumulation. Regarding interactions, 0% salinity with Zn\textsubscript{5} application recorded the highest Cu accrual, while 1% salinity with Zn\textsubscript{0} had the lowest Cu accumulation (Table 2).

The highest Mn uptake was noted for the plants grown under 0 and 0.5% salinity levels and Zn\textsubscript{0}, whereas Zn\textsubscript{10} and 1.5% salinity resulted in the lowest Mn accumulation. Regarding interaction, no salinity with Zn\textsubscript{0} application recorded the highest Mn accrual, while 1.5% salinity with all Zn levels had the lowest Mn accumulation (Table 2).

Plants grown under 1.5% salinity and Zn\textsubscript{0} resulted in the highest Fe uptake, whereas 1% salinity and Zn\textsubscript{10} resulted in the lowest Fe accrual. Regarding interaction, 1.5% salinity with Zn\textsubscript{0} recorded the highest Fe accrual, while 0.5% salinity with Zn\textsubscript{10} had the lowest Fe accumulation (Table 2).

Different growth and nutrient uptake traits had no positive correlation with each other; however, some traits were negatively correlated with each other (Fig 7). The Na accumulation

Table 2. The influence of different zinc (Zn) levels on nutrient acquisition traits and K/Na ratio of Basil (\textit{Ocimum basilicum} L.) grown under different NaCl salinity levels.

| Treatment | Na (%) | K (%) | K/Na | Zn (mg kg\textsuperscript{-1}) | Cu (mg kg\textsuperscript{-1}) | Mn (mg kg\textsuperscript{-1}) | Fe (mg kg\textsuperscript{-1}) |
|-----------|--------|-------|------|-------------------------------|------------------------------|-----------------|-----------------|
| Salinity levels |        |       |      |                               |                              |                 |                 |
| 0%        | 2.28 d | 5.82 a | 2.62 a | 45.99 ab                      | 9.29 ab                     | 168.82 a        | 147.58 b        |
| 0.5%      | 3.69 c | 4.37 b | 1.35 b | 47.36 a                       | 9.40 a                     | 167.57 a        | 88.54 d         |
| 1%        | 6.61 b | 4.27 b | 0.65 c | 43.14 c                       | 8.79 c                     | 156.84 b        | 118.87 c        |
| 1.5%      | 8.12 a | 4.38 b | 0.54 c | 44.29 bc                      | 9.00bc                     | 139.94 c        | 206.82 a        |
| LSD 0.05  | 0.18   | 0.20  | 0.23  | 2.62                          | 0.36                        | 4.48            | 6.28            |
| Zinc levels |       |       |       |                               |                              |                 |                 |
| 0 mg kg\textsuperscript{-1} | 5.24 b | 4.57 b | 1.12 b | 15.11 c                       | 8.41 c                     | 165.78 a        | 156.55 a        |
| 5 mg kg\textsuperscript{-1} | 5.54 a | 4.87 a | 1.15 b | 48.63 b                       | 9.64 a                     | 157.35 b        | 147.06 b        |
| 10 mg kg\textsuperscript{-1} | 4.75 c | 4.69 ab | 1.59 a | 71.85 a                       | 9.31 b                     | 151.75 c        | 117.75 c        |
| LSD 0.05  | 0.15   | 0.18  | 0.21  | 2.26                          | 0.31                        | 3.88            | 5.44            |
| Salinity x zinc interaction |       |       |       |                               |                              |                 |                 |
| S\textsubscript{1}Zn\textsubscript{1} | 2.27 h | 5.45 b | 2.40 b | 12.37 f                       | 7.87 fg                    | 186.10 a        | 104.03 f        |
| S\textsubscript{1}Zn\textsubscript{2} | 2.67 g | 6.00 a | 2.25 b | 56.10 c                       | 10.63 a                    | 158.47 d        | 163.23 d        |
| S\textsubscript{1}Zn\textsubscript{3} | 1.89i | 6.02 a | 3.19 a | 69.50 b                       | 9.37bcd                    | 161.90 cd       | 175.47 c        |
| S\textsubscript{2}Zn\textsubscript{1} | 5.17 e | 4.38 cd | 0.85 e | 14.00ef                       | 9.63 b                     | 170.43 b        | 96.97fg         |
| S\textsubscript{2}Zn\textsubscript{2} | 3.74 f | 4.42 cd | 1.18 d | 48.23 d                       | 9.77 b                     | 165.07bcd       | 88.57gh         |
| S\textsubscript{2}Zn\textsubscript{3} | 2.15 hi | 4.30 d | 2.02 c | 79.83 a                       | 8.80de                     | 167.20bc        | 80.10 h         |
| S\textsubscript{3}Zn\textsubscript{1} | 6.51 d | 4.21 d | 0.65 f | 16.20ef                       | 7.67 g                     | 168.33bc        | 131.73 e        |
| S\textsubscript{3}Zn\textsubscript{2} | 6.76 cd | 4.38 cd | 0.65 f | 45.07 d                       | 9.20bcd                    | 163.60bcd       | 138.03 e        |
| S\textsubscript{3}Zn\textsubscript{3} | 6.54 d | 4.21 d | 0.64 f | 68.17 b                       | 9.50bc                     | 138.60 e        | 86.83gh         |
| S\textsubscript{4}Zn\textsubscript{1} | 6.98 c | 4.21 d | 0.60 f | 17.87 e                       | 8.47ef                     | 138.27 e        | 293.47 a        |
| S\textsubscript{4}Zn\textsubscript{2} | 8.98 a | 4.68 c | 0.52 f | 45.10 d                       | 8.97cde                    | 142.27 e        | 198.40 b        |
| S\textsubscript{4}Zn\textsubscript{3} | 8.41 b | 4.23 d | 0.50 f | 69.90 b                       | 9.57bc                     | 139.30 e        | 128.60 e        |
| LSD 0.05  | 0.31   | 0.36  | 0.28  | 4.53                          | 0.63                        | 7.76            | 10.88           |

S\textsubscript{1} = 0% NaCl, S\textsubscript{2} = 0.5% NaCl, S\textsubscript{3} = 1% NaCl, S\textsubscript{4} = 1.5% NaCl, Zn\textsubscript{1} = 0 mg kg\textsuperscript{-1} Zn, Zn\textsubscript{2} = 5 mg kg\textsuperscript{-1} Zn, Zn\textsubscript{3} = 10 mg kg\textsuperscript{-1} Zn. Any two means followed by same letter within a column are statistically similar to each other (p > 0.05)

https://doi.org/10.1371/journal.pone.0246493.1002

https://doi.org/10.1371/journal.pone.0246493.t002
had significant negative correlations with biomass production, chlorophyll index, K/Na ratio and accumulation of Mn and K (Fig 7). All other traits exhibited no positive/negative correlation.

**Discussion**

Salinity significantly reduces plant growth depending on salt concentration and growth stage of the plants [6, 7]. Inhibition of photosynthesis is among the first indicators of salinity stress. Numerous studies have reported photosynthetic changes in crop plants in response to salinity stress [36–39]. Generally, photosynthesis is retarded by increasing salt levels [36, 37, 40, 41]. Stomatal and non-stomatal factors are responsible for retarded photosynthesis under salinity stress [42]. Salinity decreases CO₂ assimilation and diffusion from the stomata to mesophyll cells [43] or alters photosynthetic mechanism [44].

Biomass production and chlorophyll index were reduced under increasing salinity levels in the current study. The decreased chlorophyll index and biomass production can be explained with ion toxicity caused by excessive salt levels. Results revealed that damage caused by salinity decreased with Zn application. The positive effect of Zn application on reduction of salt damage has been reported by several researchers [22–24, 45, 46]. Daneshbakhsh et al. [22] reported that negative effect of salt decreased with Zn application depending on genotype and salt concentration. In addition, K accumulation decreased under salinity; however, Zn application improved K uptake. Similarly, Na accumulation increased under salinity, while Zn application decreased Na concentration. Similar results have been reported in the current study. Results revealed significant decrease in biomass production with increasing salinity levels. However, basil managed to survive high salt stress. With increasing salinity levels, decreases in growth
were higher in roots than in leaves [47]. The increased Na accumulation and a reduction in K, Zn, Cu and Mn concentrations could be responsible for decreased biomass. An earlier study has also reported that biomass of basil was decreased with increasing salinity [6, 7].

Nutrient uptake was significantly altered by different salinity levels included in the study. Decline in ion accumulation and selectivity has been well documented in wheat [48], sorghum [49], maize [50], barley [51] and rice [52]. However, basil exhibited a strong selectivity for K uptake, which improved K/Na ratio. Zinc reduces excessive Na uptake under saline environments by affecting structural integrity and permeability of stem cell membrane [23]. Zinc nutrition is effective in decreasing Na accumulation and improving K/Na ratio of plants under salinity. Therefore, cell membranes show high permeability or leakage of some compounds from the roots under Zn deficiency [25]. Zinc deficiency can lead to accumulation of toxic ions such as Na and Cl.

Different growth and nutrient uptake traits had no positive correlation with each other; however, some traits were negatively correlated (Fig 7). The Na accumulation had significant negative correlations with biomass production, chlorophyll index, K/Na ratio and accumulation of Mn and K (Fig 7). All other traits exhibited no positive/negative correlation. This indicated that Na accumulation has been the prime source of decreased growth and disturbed nutrient acquisition traits in the current study. This study suggested that field trials are necessary in saline and Zn deficit regions. In addition, Zn has potential to play a protective effect up to a certain extent in ameliorating salt damage.

Author Contributions

Conceptualization: Inci Tolay.
Data curation: Inci Tolay.
Formal analysis: Inci Tolay.
Investigation: Inci Tolay.
Methodology: Inci Tolay.
Project administration: Inci Tolay.
Writing – original draft: Inci Tolay.
Writing – review & editing: Inci Tolay.

References
1. Nadeem F, Azhar M, Anwar-ul-Haq M, Sabir M, Samreen T, Tufail A, et al. Comparative response of two rice (Oryza sativa L.) cultivars to applied zinc and manganese for mitigation of salt stress. J Soil Sci Plant Nutr. 2020; 20: 2059–2072. https://doi.org/10.1007/s42729-020-00275-1
2. Tester M. Na⁺ Tolerance and Na⁺ Transport in Higher Plants. Ann Bot. 2003; 91: 503–527. https://doi.org/10.1093/aob/mcg058 PMID: 12646496
3. Munns R, Tester M. Mechanisms of salinity tolerance. Annu Rev Plant Biol. 2008; 59: 651–681. https://doi.org/10.1146/annurev.arplant.59.032807.092911 PMID: 18444910
4. Martínez-Beltran J, Manzur CL. Proceedings of the International Salinity Forum. 2005. https://doi.org/10.1128/AAC.49.12.5172-5175.2005 PMID: 16304197
5. Qadir M, Quillérou E, Nangia V, Murtaza G, Singh M, Thomas RJ, et al. Economics of salt-induced land degradation and restoration. Nat Resour Forum. 2014; 38: 282–295. https://doi.org/10.1111/1477-8947.12054
6. Tarchoune I, Degli’innocenti E, Kaddour R, Guidi L, Lachaïl M, Navari-Izzo F, et al. Effects of NaCl or Na₂SO₄ salinity on plant growth, ion content and photosynthetic activity in Ocimum basilicum L. Acta Physiol Plant. 2012; 34: 607–615.
7. Tarchoune I, Sgherri C, Baâtour O, Izzo R, Lachaâl M, Navari-Izzo F, et al. Effects of oxidative stress caused by NaCl or Na$_2$SO$_4$ excess on lipoic acid and tocopherols in Genovese and Fine basil (Ocimum basilicum). Ann Appl Biol. 2013; 163: 23–32.

8. Kendirli B, Cakmak B, Ucar Y. Salinity in the southeastern anatolia project (GAP), Turkey: Issues and options. Irrigation and Drainage. 2005. 115–122. https://doi.org/10.1002/ird.157

9. Singh RB, Minhas PS, Chauhan CPS, Gupta RK. Effect of high salinity and SAR waters on salinization, sodication and yields of pearl-millet and wheat. Agric Water Manag. 1992; 21: 93–105. https://doi.org/10.1016/0378-3774(92)90085-B

10. Rhode JD. Instrumental Field Methods of Salinity Appraisal. John Wiley & Sons, Ltd; 2012. pp. 231–248. https://doi.org/10.2136/sssaspecpub30.c12

11. Hoffman Glenn J., Shalhevet Joseph, Hoffman Glenn J., Shalhevet Joseph. Chapter 7. Controlling Salinity. Design and Operation of Farm Irrigation Systems, 2nd Edition. American Society of Agricultural and Biological Engineers; 2013. pp. 160–207. https://doi.org/10.10131/2013.23690

12. Carregosa F, Figueira E, Gil AM, Pereira S, Pinto J, Soares AMVM, et al. Tolerance of Venerupis philippinarum to salinity: Osmotic and metabolic aspects. Comp Biochem Physiol—A Mol Integr Physiol. 2014; 171: 36–43. https://doi.org/10.1016/j.cbpa.2014.02.009 PMID: 24556070

13. Tanji KK, Kielen NC. Agricultural drainage water management in arid and semi-arid areas. FAO; 2002.

14. Abbas G, Amjad M, Saqib M, Murtaza B, Asif Naeem M, Shabbir A, et al. Soil sodicity is more detrimental than salinity for quinoa (Chenopodium quinoa Wild.): A multivariate comparison of physiological, biochemical and nutritional quality attributes. J Agron Crop Sci. 2020; https://doi.org/10.1111/jac.12363 PMID: 32063682

15. Marschner P. Marschner’s Mineral Nutrition of Higher Plants: Third Edition. 2011. https://doi.org/10.10131/C2009-0-63043-9

16. Shabala L, Mackay A, Tian Y, Jacobsen SE, Zhou D, Shabala S. Oxidative stress protection and stoma-tal patterning as components of salinity tolerance mechanism in quinoa (Chenopodium quinoa). Physiol Plant. 2012; 146: 26–38. https://doi.org/10.1111/j.1399-3054.2012.01599.x PMID: 22324972

17. Zhu JK. Cell signaling under salt, water and cold stresses. Current opinion in plant biology. 2001. 401–406. https://doi.org/10.1016/s1360-1385(00)20111-jac.12363 PMID: 22324972

18. Shanag M, Reading LP, Baumgartl T. Effect of physical amendments on salt leaching characteristics for reclamation. Geoderma. 2017; 292: 96–110.

19. Zhu J.-K. Plant salt tolerance. Trends Plant Sci. 2001; 6: 66–71. https://doi.org/10.1016/s1360-1385(00)01838-0 PMID: 11173290

20. Tavallali V, Rahemi M, Mafroun M, Panahi B, Karimi S, Ramezanian A, et al. Zinc influence and salt stress on photosynthesis, water relations, and carbonic anhydrase activity in pistachio. Sci Hortic. 2009; 123: 272–279. https://doi.org/10.1016/j.scienta.2009.09.006

21. Daneshbaksh B, Khoshtofigarmanesh AH, Shariatmadari H, Cakmak I. Phytosiderophore release by wheat genotypes differing in zinc deficiency tolerance grown with Zn-free nutrient solution as affected by salinity. J Plant Physiol. 2013; 170: 41–46. https://doi.org/10.1016/j.jplph.2012.08.016 PMID: 23122914

22. Aktas H, Abak K, Ozturk L, Cakmak I. The effect of zinc on growth and shoot concentrations of sodium and potassium in pepper plants under salinity stress. Turkish J Agric For. 2006; 30: 407–412. https://doi.org/10.3906/tar-0609-2

23. Salieh J, Mafroun M, Safarzadeh S, Gholami A. Growth, mineral composition, and biochemical changes of broad bean as affected by sodium chloride and zinc levels and sources. Commun Soil Sci Plant Anal. 2009; 40: 3046–3060. https://doi.org/10.1080/00103620903261619

24. Yesil E. Genetic variation for salt and zinc deficiency tolerance in Aegilops tauschii. 2008. Ph.D Thesis.

25. Lee S-J, Umano K, Shibamoto T, Lee K-G. Identification of volatile components in basil (Ocimum basilicum L.) and thyme leaves (Thymus vulgaris L.) and their antioxidant properties. Food Chem. 2005; 91: 131–137.

26. Hassanpouraghdam M, Gohari G, Tabatabaei S, Dadpour M, Shirdel M. NaCl salinity and Zn foliar application influence essential oil composition of basil (Ocimum basilicum L.). Acta Agric Slov. 2011; 97: 93–98. https://doi.org/10.2478/v10014-011-0004-x

27. Nurzyńska-Wierdak R. Sweet basil essential oil composition: relationship between cultivar, foliar feeding with nitrogen and oil content. J Essent Oil Res. 2012; 24: 217–227. https://doi.org/10.1080/10412905.2012.676763

28. Jackson ML. New Books. J Agric Food Chem. 1959; 7: 138–138. https://doi.org/10.1021/jf60096a605
30. Bouyoucos GJ. A Recalibration of the Hydrometer Method for Making Mechanical Analysis of Soils. 1. Agron J. 1951; 43: 434–438. https://doi.org/10.2134/agronj1951.000219620043000900005x

31. Walkley A, Black IA. An examination of the digi-jareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 1934; 37: 29–38. https://doi.org/10.1097/00010694-193401000-00003

32. Olsen SR. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. US Department of Agriculture; 1954.

33. Carson PL. Recommended potassium test. Bull Dep Agric Econ ND Agric Exp Stn ND State Univ Agric Appl Sci. 1975.

34. Lindsay WL, Norvell WA. Development of a DTPA Soil Test for Zinc, Iron, Manganese, and Copper. Soil Sci Soc Am J. 1978; 42: 421–428. https://doi.org/10.2136/sssaj1978.03615995004200030009x

35. Farooq S, Tad S, Onen H, Gunal H, Cakir H, Ozaslan C. Range expansion potential of two co-occurring invasive vines to marginal habitats in Turkey. Acta Oecologica. 2017; 84: 23–33. https://doi.org/10.1016/j.actao.2017.08.004

36. Qiu N, Lu Q, Lu C. Photosynthesis, photosystem II efficiency and the xanthophyll cycle in the salt adapted halophyte Atriplex centralasiatica. New Phytol. 2003; 159: 479–486.

37. Koyro H-W. Effect of salinity on growth, photosynthesis, water relations and solute composition of the potential cash crop halophyte Plantago coronopus (L.). Environ Exp Bot. 2006; 56: 136–146.

38. Arif Y, Singh P, Siddiqui H, Bajguz A, Hayat S. Salinity induced physiological and biochemical changes in plants: An omic approach towards salt stress tolerance. Plant Physiol Biochem. 2020; 156: 64–77. https://doi.org/10.1016/j.plaphy.2020.08.042 PMID: 32906023

39. Pan T, Liu M, Kreslavski VD, Zharmukhamedov SK, Nie C, Yu M, et al. Non-stomatal limitation of photosynthesis by soil salinity. Crit Rev Environ Sci Technol. 2020; 1–35.

40. Sudhir P, Murthy SDS. Effects of salt stress on basic processes of photosynthesis. Photosynthetica. 2004; 42: 481–486.

41. Chaves MM, Flexas J, Pinheiro C. Photosynthesis under drought and salt stress: regulation mechanisms from whole plant to cell. Ann Bot. 2009; 103: 551–560. https://doi.org/10.1093/aob/mcn125 PMID: 18662937

42. Naumann JC, Young DR, Anderson JE. Linking leaf chlorophyll fluorescence properties to physiological responses for detection of salt and drought stress in coastal plant species. Physiol Plant. 2007; 131: 422–433. https://doi.org/10.1111/j.1399-3054.2007.00973.x PMID: 18251881

43. Flexas J, Diaz Espejo A, Galmeas J, Kaldenhoff R, Medrano H, Ribas Carbo M. Rapid variations of mesophyll conductance in response to changes in CO$_2$ concentration around leaves. Plant Cell Environ. 2007; 30: 1284–1298.

44. Lawlor DW, Cornic G. Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants. Plant Cell Environ. 2002; 25: 275–294.

45. Daneshbaksh B, Khoshgoftaranesh AH, Shariatmadari H, Cakmak I. Effect of zinc nutrition on salinity-induced oxidative damages in wheat genotypes differing in zinc deficiency tolerance. Acta Physiol Plant. 2013; 35: 881–889.

46. Khoshgoftar AH, Shariatmadari H, Karimian M, Khajehpour MR. Responses of wheat genotypes to zinc fertilization under saline soil conditions. J Plant Nutr. 2006; 29: 1543–1556. https://doi.org/10.1080/01904160600848771

47. Caliskan O, Radusiene J, Temizel KE, Staunis Z, Cirak C, Kurt D, et al. The effects of salt and drought stress on phenolic accumulation in greenhouse-grown Hypericum pruinatum. Ital J Agron. 2017; 12: 271–275. https://doi.org/10.4081/ija.2017.918

48. Housham S, Arzani A, Maibody SAM, Feizi M. Evaluation of salt-tolerant genotypes of durum wheat derived from in vitro and field experiments. F Crop Res. 2005; 91: 345–354.

49. Netondo GW, Onyango JC, Beck E. Sorghum and salinity: II. Gas exchange and chlorophyll fluorescence of sorghum under salt stress. Crop Sci. 2004; 44: 806–811.

50. Cramer GR, Alberico GJ, Schmidt C. Salt tolerance is not associated with the sodium accumulation of two maize hybrids. Funct Plant Biol. 1994; 21: 675–692.

51. Degl’Innocenti E, Hafsi C, Guidi L, Navari-Izzo F. The effect of salinity on photosynthetic activity in potassium-deficient barley species. J Plant Physiol. 2009; 166: 1968–1981. https://doi.org/10.1016/j.jplph.2009.06.013 PMID: 19604600

52. Saleque MA, Choudhury NN, Rezaul Karim SM, Panaullah GM. Mineral nutrition and yield of four rice genotypes in the farmers’ fields of salt-affected soils. J Plant Nutr. 2005; 28: 865–875.