

Investigation of the Usage of *Limonium gmelinii* in Phytoremediation

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Abstract In this study, "*Limonium gmelinii*", which can be valuable as a halophyte that can be used for the improvement of arid and salty areas and for bringing them into agriculture, was researched. The experiment was carried out as 1 plant x 1 soil x 3 subjects (NaCl, Na₂SO₄, B) x 4 doses x 5 replications, in a greenhouse environment. In NaCl and Na₂SO₄ treatments, Na values increased in the plant compared to the soil, and increased up to 10500 ppm. In NaCl treatments, Cl accumulation was higher in the plant than in the soil, and increased to 33700 ppm. In Na₂SO₄ treatments, SO₄ values in the plant were higher than in the soil and increased up to 59300 ppm. In the Na₂SO₄ treatments, there was a noticeable accumulation of salt on the leaves. In B treatments, while there was no significant increase in soil B values, there was an increase in the plant and then a decrease was observed. It is thought that the plant removes and tolerates B toxicity by removing high boron concentration with its salt sacs and salt glands. With the study, it was determined that *Limonium gmelinii* eliminated the toxicity in the soil by incorporating different doses of these substances applied to the soil.

Keywords *Limonium gmelinii*, Boron Toxicity, Phytoremediation, Halophyte Plant, Salinity

1. Introduction

Especially with the problems such as salinity, drought, global warming and climate change that threaten the whole world, it has become more important to use our existing

agricultural lands more efficiently, to bring the unused lands to agriculture, to determine the plants that can adapt to such problematic areas and survive. It is very important to disseminate strong plants with high economic value in the cultivation of salty and boron-toxic soils. There are few studies on the use of ornamental plants for these purposes. Phytoremediation studies have also been carried out mostly on heavy metal pollution, and studies on salinity are few.

Today, while the need for food is increasing exponentially, the last limit of arable land has been reached, and it has become urgent to rehabilitate polluted and salty lands and bring them into agriculture.

It has been stated that approximately 1 billion hectares of land in more than 100 countries around the world are affected by salt. It is estimated that there are more than ten million hectares of areas exposed to salinity annually, of which 3% is agricultural land. About 20% of the irrigable agricultural land has been affected by salinity and agricultural production has decreased significantly [17]. This problem is not only a problem of developing countries but also the problem of countries using advanced technology in agriculture. Pakistan (3.2 million ha), India (20 million ha), China (7 million ha) and the United States (5.2 million ha) constitute approximately 35 million ha of the total irrigable agricultural land (60 million ha) affected by salinity. Approximately 25 million hectares of irrigated areas affected by salinization are located in Afghanistan, Egypt, Iraq, Kazakhstan, Turkmenistan, Mexico, Syria and Turkey. Considering the situation in Turkey, it has been reported that there is a salinity problem or threat in approximately 4 million hectares of land. Considering the usage patterns of the lands in Turkey, it is known that there

is a barrenness problem in 163,638 hectares of dry farming areas, 449,709 hectares of irrigated agricultural areas, 9,050 hectares of vineyard-garden areas, 733,422 hectares of meadow-pasture areas and 11,436 hectares of forest areas [24]. Due to the climate zone it is in, Turkey creates an ideal environment for the formation of salinity and alkalinity. Salts, which melt with low rainfall, form salt layers on the soil surface accumulating in areas used by plants effectively with the effect of excessive heat. Carsamba Plain, Tarsus Plain and some parts of Çukurova, Salt Lake, Çumra Plain, Iğdır Plain, Gediz Basin, Menemen, Manisa, Salihli, Alaşehir Plains, Aşağı Kırıklar, Büyük Menderes Basin, Gölemerli Plain, local areas in some parts of Meriç Basin, in Thrace Region are the most typical examples of this situation [2].

Salty alkaline soils formed in arid and semi-arid regions have higher boron contents than other soils. Boron toxicity can occur naturally in soils, but it also arises from chimney ash, industrial wastes and chemicals, especially as a result of the use of water containing high B or compost fertilizers, or in the case of aquaculture in the vicinity of thermal power plants using lignite coal [2]. Among all potential sources, the most important effect of irrigation water is that it causes an increase in soil boron content. Boron concentration is usually high in saline soils or salty well waters [8].

Turkey, especially the Western Anatolia Region, has 61% of the world's B reserves, and B pollution has been an important problem affecting water resources and agricultural lands in the region. The main boron production in Turkey is carried out in Bigadiç M. Kemalpaşa, Emet and Kırkı regions located between Kütahya and Balıkesir city centers, these mine production centers are located in the Simav, Kirmastı and M. Kemalpaşa drainage basins. Boron drainage and washing waters discharged to water resources during production pollute both Simav River, Uluabat Lake and the Marmara Sea. There is no other important option other than the Simav River tributaries for irrigation of agricultural lands in the region. For this reason, the Simav River has been affected by 117,274 hectares of agricultural land in the drainage basin and 94,358 hectares of boron pollution. Moreover, due to waters with high boron content, high levels of B pollution have been observed in the soils of Afyon, Aksaray, Bigadiç Burdur, Konya-Ereğli, Eskişehir, Germencik Ömerbeyli, Iğdır, Karasaz, Kayseri, Yüksekova and Salihli regions [18].

Considering that the limited values of usable agricultural lands in the world have been reached, it is of great importance to rehabilitate the degraded lands and bring them into agriculture. The salinity of soils has been a problem in every period of human life. A large part of the land on earth cannot be cultivated due to salinity. Soil salinity causes great agricultural damage by decreasing the crop yield of plants. The elimination of soil salinity is very important from an economic point of view. However, the elimination of salinity is not only economical but also very

difficult [9].

Reclamation of boron-contaminated soils is even more difficult than the reclamation of soils with salinity problems. Since boron is washed out of the soil more slowly than other salts, much more washing water is needed. In the improvement of boron soils, 2 or 3 times more water is needed than the amount of water used in the improvement of saline soils. Furthermore, it is more difficult to wash boron from fine-textured soils than from coarse-textured soils. The very slow movement of boron in the soil makes it difficult to wash it from the soil. The reasons such as limited use of boron-free clean irrigation water and the need for more water use seem to be limiting factors for the success of this application [16].

Despite the rapid increase in the world population day by day, the low arable land raises the problem of developing better quality and productive plants. Plants are faced with many adverse environmental conditions such as salinity, cold, drought and climate change. Understanding the potential power of plants to cope with these adverse environmental conditions will be useful in solving the problems. Based on this, the present study on the effects of *Limonium gmelinii* is important.

Developed countries tried to plan a natural treatment system and as a result "Plant Breeding Systems" was created. The use of plants or plant products to restore or stabilize polluted areas, the selective removal, separation and purification of pollution by the plant is known as phytoremediation, and the natural abilities of plants such as removing, accumulating, storing or decomposing organic or inorganic materials are advantageous [22,21].

Phytoremediation has come to the fore, especially with the environmental pollution caused by the nuclear explosion in Chernobyl in 1986. Plants played a key role in trying to clean up the pollution that occurs in an area with a diameter of more than 100 km with an unmanned mechanism, and studies to increase these abilities of plants gained momentum [23].

While most of the physicochemical technologies used for soil treatment completely destroy the biological activity in the soil and transform the soil into an unsuitable environment for plant growth, the phytoremediation method preserves the biological properties and physical structure of the soil [19].

As a result of the assumption that the world will become increasingly arid in years, these plants, which can survive in salty environments and with less water, carry hope for the future of the increasingly arid world. For this reason, introducing plants that can grow in soils that consume less water and increased salinity due to drought and encouraging studies on the subject gain more importance today. Especially ornamental plants constitute the hidden potential of Turkish agriculture. Many plants have been used in phytoremediation to date, but there are very few studies on the use of ornamental plants in the improvement of contaminated soils. The pollution problem in the soil is

eliminated by using ornamental plants, which provide a beautiful view of the environment. Moreover, economic gain can be achieved by harvesting these plants and using them in different areas.

In this study, it was aimed to make the areas with soil salinity problems usable by the phytoremediation method. In addition, it was aimed to contribute to the studies of boron toxicity removal with the phytoremediation method, with identification and dissemination of *Limonium gmelinii* as an alternative ornamental plant by determining the salt ion status from the soil. Moreover, it was aimed to contribute to the research that can be done on the determination of other usage areas, to suggest it as an alternative plant for salty and high sodium soils according to the results of the study, to reveal its effect on soils with boron toxicity and to evaluate its usability in phytoremediation. Furthermore, it was aimed to contribute to the use of this plant, which grows naturally in salty regions, in the field of agriculture, to contribute to Turkey's economy by providing areas that can be improved by using this plant and brought into agriculture.

2. Materials and Methods

Limonium gmelinii, which grows in coastal and inland areas, has an herbaceous structure with a leaf size of 10-30 x 2-8 cm, a flower stalk length of 20-60 cm, and blue flowers, were used as material in the study. The flowering period covers the months of July-August and the plant is not endemic. Its family is *Plumbaginaceae*, its genus is *Limonium* MILLER, and its taxon is *Limonium gmelinii* (Willd.) O. KUNTZE. It can grow in soils with soil pH of 6.1-6.5 (slightly acidic), 6.6-7.5 (neutral), and 7.6-7.8 (slightly alkaline) [3].



Figure 1. *Limonium gmelinii* plants [3]

Its distribution in Turkey is Istanbul, Iğdır, Amasya, Çanakkale, Erzincan, Eskişehir, Muğla, Niğde, Sivas, Tekirdağ, and its general distribution in Central Europe, the Balkans, Crimea, Caucasus, Iran and Central Asia [3]. It is common in the eastern part of Hungary. Typical habitats are salty. It is frequently seen in marsh meadows, salty areas and abandoned areas [12].

The experiment was arranged as 1 Plant x 1 Soil x 3 Subjects (NaCl, Na₂SO₄, B) x 4 Doses x 5 Replications according to the randomized blocks trial design, and was carried out using 60 pots in a modern glasshouse in Akdeniz University, Faculty of Agriculture. The seeds were grown in viols with the peat-perlite mixture for 72 days and then transferred to 23-liter black plastic pots. The pots used in the treatment were filled with silty loam (48.7% silt, 34.5% sand, 16.8% clay) soils taken from 0-20 cm depth from the Tehnelli series soil surface located in Akdeniz University, Aksu Mandirlar Research and Application Station.

Table 1. Some characteristics of the experiment soil

Soil	Unit	Analysis Result
pH	--	7.6
EC	dS/m	0.44
Organic matter	%	0.92
CaCO ₃	%	48.69
Field capacity	%	26.50
Extractable Na	ppm	29.13
B Beneficial to the plant	ppm	0.41
Soluble Cl	ppm	40
Extractable SO ₄	ppm	0.96

Some values of the experiment soil are given in Table 1. Initially, 4 plants were planted in the pots. Then, thinning was done and 3 plants were left in each pot. Before starting the applied irrigations, EC and pH measurements were made and the pH value of the control irrigation water was determined as 6.8 and the EC value as 0.69 mS/cm (low-salinity). The EC values for NaCl treatments were 6.4 mS/cm (saline), 12.04 mS/cm (high-salinity), 16.80 mS/cm (severe salinity), and EC values for Na₂SO₄ treatments were 10.08 mS/cm (high-salinity), 17.84 mS/cm (severe salinity), 24 mS/cm (severe salinity). After the plants were transferred to the pots, they were irrigated daily for a 2.5-month adaptation period so that they could adapt to the greenhouse environment. During the experiment period, irrigation treatments were carried out considering approximately 70% of the field capacity. Thematic irrigations were applied as 0.5 liters 9 times in 10-day periods throughout the development period. During the summer period, daily irrigations were continued, and with the decrease in temperatures, irrigation was continued every two days.

Different compounds and different concentrations of these compounds (0, 50, 100, 150 mM for NaCl, 0, 50, 100, 150 mM for Na₂SO₄, 0, 5, 10, 15 mg/l for B) were used as the experiment factor. The values used were determined by considering similar literature studies and limit values. Since the form of boron mineral that can be taken by plants

is Boric acid (H_3BO_3), B doses were applied in the form of H_3BO_3 .

The Cl and B values for the plant were determined by the wet burning-ICP method, the Na value was determined by the ICP-OES method and the SO_4 value was determined by the Turbidimetric method [15]. Extractable Na values were determined by reading the extract obtained by saturating the soil with ammonium acetate by the ICP method [25]. Soil texture was determined by the hydrometer method [7]. Soil pH was measured in a 1:2.5 soil:water mixture with a pH-meter and soil electrical conductivity (EC) was measured in a 1:2.5 soil:water mixture with EC-meter [13]. Organic matter was found according to the Modified Walkley-Black method [6]. Percent lime in the soil ($CaCO_3$) was determined by the Scheibler calcimeter [10]. The amount of water retained in the soil sample was determined under 1/3 atmospheric pressure using a pressure membrane instrument, and the field capacity was determined using undisturbed soil samples [6]. Soluble Cl was determined by the Mohr-Titrimetric method [14]. The B useful for the plant was determined in the spectrophotometer by the Azomethine-H method [14]. Extractable SO_4 was determined by the turbidimetric method in soil extracted with Potassium dihydrogen phosphate (KH_2PO_4) [14]. For plant analysis, plant leaves were used.

At the end of the experiment, descriptive statistics are presented with the mean. Normality assumption was evaluated with the Shapiro Wilks test. In the analysis of the difference between the numerical data of more than two groups, a one-way analysis of variance (ANOVA) was performed for normally distributed data. Duncan's multiple range test was used to determine the significance levels of the differences between the treatments. The Kruskal Wallis test was used in the analysis of data that did not show normal distribution. As a result of the significant difference, Bonferroni-Dunn Procedure was applied in pairwise comparisons. All statistical calculations were made on the computer using the SAS 9.4 program. Moreover, $P < 0.05$ was considered statistically significant.

3. Results and Discussion

In this study, the phytoremediation effect of *Limonium Gmelinii* (Siberian statice) in environments where different concentrations of NaCl, Na_2SO_4 and B treatments were applied was investigated. To determine the effect of salty and boron conditions on Na, Cl, B, and SO_4 values, 0, 50, 100, and 150 mM concentrations of NaCl and Na_2SO_4 salts and 0, 5, 10, and 15 mg/l concentrations of B were applied.

3.1. Plant Na Values

To determine plant Na values, plant leaves were analyzed. Most designs that use plant analysis to assess nutrient status are based on the relationship between nutrient concentration and the yield or growth of a plant or

plant part. There are different ways to express concentration, but the most common is percent (%) and mg/kg (ppm). Results are given in % as ppm is used for micronutrients and percentage is commonly used for major nutrients. NC 1=50 mM NaCl, NC 2=100 mM NaCl, NC 3=150 mM NaCl, NS 1=50 mM Na_2SO_4 , NS 2=100 mM Na_2SO_4 , NS 3=150 mM Na_2SO_4 , B 1=5 mg/l, B 2=10 mg/l, B 3=15 mg/l used in the all figures. The effect of NaCl treatments on plant Na values was found to be significant, with $P=0.0001 < 0.05$. It is seen that Na values increase with increasing application doses. The effect of Na_2SO_4 treatments on plant Na values was $P=0.0001 < 0.05$, and there was a statistical difference. It is understood that Na values increase with increasing doses. The effect of NaCl and Na_2SO_4 treatments on plant Na value was found to be significant since $P=0.0001 < 0.05$.

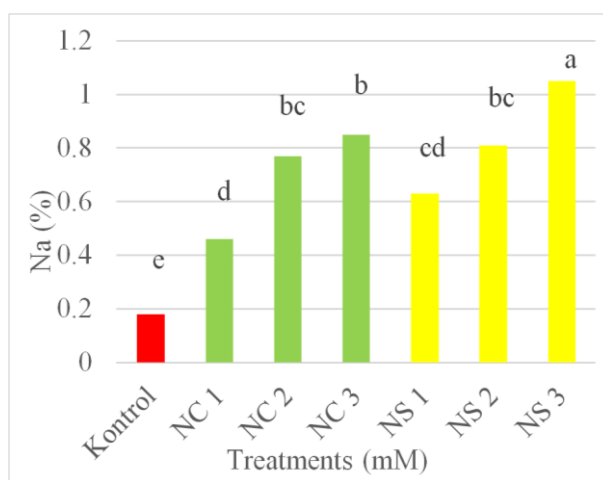


Figure 2. Change in plant Na values between NaCl and Na_2SO_4 treatments

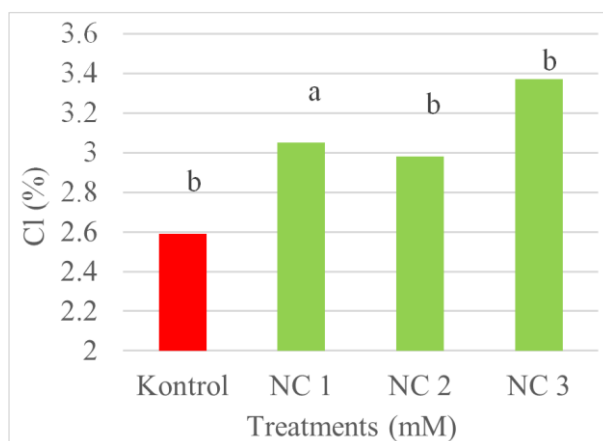


Figure 3. The effect of NaCl treatments on plant Cl values

It is seen in Figure 2 that there is a higher increase in Na values in Na_2SO_4 treatments compared to NaCl treatments. The highest Na value was obtained in the treatment of 150 mM Na_2SO_4 . In B treatments, the effect on Na values was $P=0.146 > 0.05$, and there was no statistical difference. In

general, there was no significant effect of B treatments in terms of Na values.

3.2. Plant Cl Values

As an essential micronutrient, Cl plays a role in enzyme activation in the cytoplasm, oxygen generation during photosynthesis, stabilization of membrane potential, and maintenance of turgor pressure and pH of plant cells. Excessive accumulation of Cl has even more harmful effects than Na in destabilizing cells [26]. The effect of NaCl treatments on plant Cl values was found to be significant, with $P=0.002<0.05$.

When Figure 3 is examined, Cl values increased with NaCl treatments in general. The effect of Na_2SO_4 treatments on Cl values in the plant was found to be significant with $P=0.031<0.05$. The effect of B treatments was $P=0.358>0.05$, and there was no statistical difference which is why it is not presented in the graph below.

In Figure 4, we observe that as Na_2SO_4 doses increased Cl values decreased. Especially with 150 mM Na_2SO_4 application doses (NS 3) Cl values were recorded at their lowest levels.

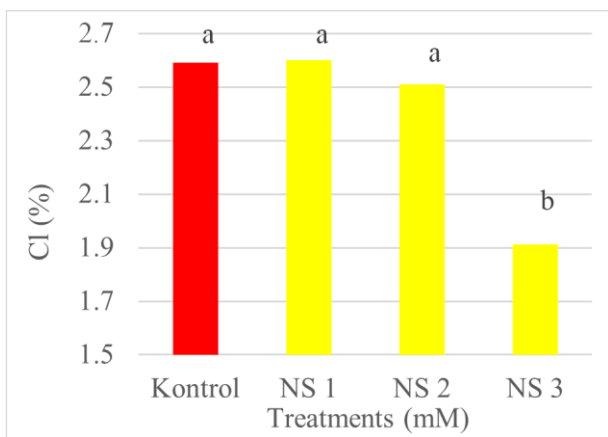


Figure 4. The effect of Na_2SO_4 treatments on plant Cl values

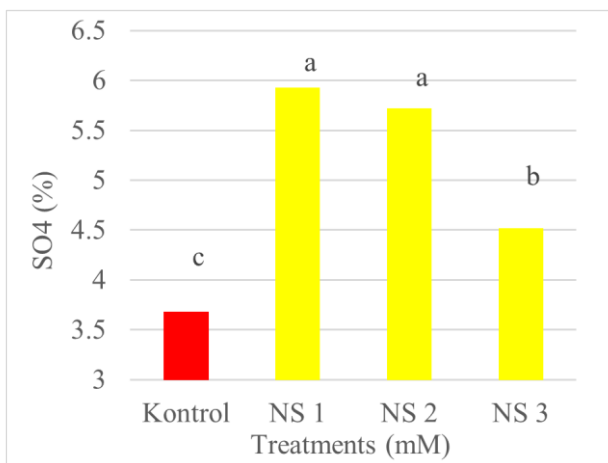


Figure 5. The effect of Na_2SO_4 treatments on plant SO_4 values

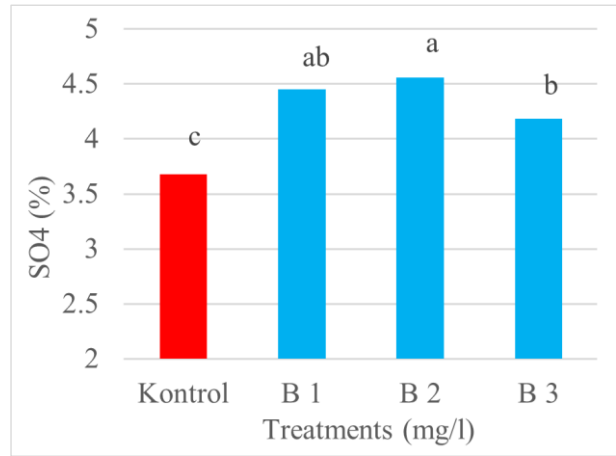


Figure 6. Effect of B treatments on plant SO_4 values

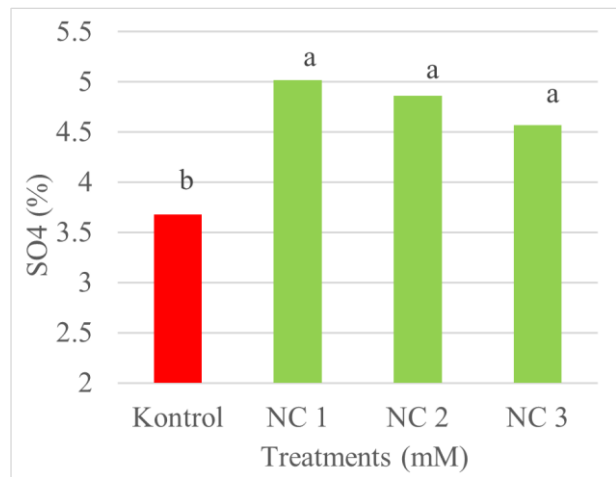


Figure 7. The effect of NaCl treatments on plant SO_4 values

3.3. Plant SO_4 Values

The effect of Na_2SO_4 treatments on plant SO_4 values was $P=0.0001<0.05$ and a statistical difference was found.

Looking at Figure 5, the values increased compared to the control. While the highest value was obtained at 50 mM, SO_4 values tended to decrease with the increase in dose, being removed from the plant body by salt sacs and salt glands. The effect of B treatments on SO_4 was $P=0.0001<0.05$ and a statistical difference was found. While the control value was 3.68%, it increased up to 4.56% with treatments (Figure 6). The effect of NaCl treatments on plant SO_4 values was $P=0.0001<0.05$ and a statistically significant difference was found. There was an overall increase in values compared to the control, but a decrease in values occurred with increasing doses (Figure 7). This can be explained by the characteristics of halophytes that enable them to survive in saline environments, succulence that enables them to keep the salt concentration at a dilute level, a high internal ion concentration and ion uptake capacity to ensure water intake, synthesizing and accumulating organic compounds

that enable to continue water intake, keeping salt in vacuoles and removing salt from the plant body with salt sacs [4,1].

3.4. Plant B Values

The effect of B treatments on plant B content was $P=0.858>0.05$, and there was no statistical difference. In the 5 mg/l B treatment, an increase was observed compared to the control, and a decrease was observed in the values with the increase in dose. It is thought that excess B accumulated at 10-15 mg/l was removed from the plant. The effect of NaCl treatments was $P=0.232>0.05$ and the effect of Na_2SO_4 treatments was $P=0.114>0.05$, and there was no statistically significant difference. A decrease in B values was observed at high saline levels. Banon et al. [5] stated that high salinity and boron occur together in irrigation waters in arid climates. In the study where they investigated the effects of high salinity (2-9 dS/m) and high boron (1-10 mg/l) on geranium plants in a greenhouse environment, it was found that there was a decrease in boron toxicity at a high saline level compared to low saline level.

Özbek [23] determined the Cd contents by collecting 48 plant samples growing around 46 zinc-lead mines in the study. The highest available cadmium was found in the soil with 39 mg kg⁻¹. In plants, on the other hand, it was observed that the highest amount of Cd was in the roots of *Plantago lanceolata* L. with 217 mg kg⁻¹, while 24.5 mg kg⁻¹ Cd accumulated in the same plant stem. Accordingly, *Plantago lanceolata* L took high levels of cadmium to its roots but partially transmitted it to the stem. *Silene compacta* Fischer, which is widely found in the sampling areas, did not accumulate Cd although it was grown in soils with high Cd content potential. The highest Cd content was observed in *Hymenocarpus circinnatus* L., with 111 mg kg⁻¹ on roots with 20 mg kg⁻¹ available Cd level. *Hymenocarpus circinnatus* L., which accumulated 7.21 mg kg⁻¹ Cd on the stem at the same dose, took cadmium into its roots, but it was stated that it could not transmit it to the stem at the same rate. As seen in the *Limonium gmelinii* plant may have gathered Cd elements on its roots as shown in the example.

3.5. Soil Na Values

The effect of NaCl treatments on the extractable Na values in the soil was significant since $P=0.0001<0.05$. With treatments, Na values increased from 79.71 ppm in control to 679.64 ppm with 150 mM NaCl treatment.

The effect of Na_2SO_4 treatments on Na values was $P=0.0001<0.05$, and there was a statistically significant difference. Moreover, the Na value increased up to 1232.22 ppm with treatments.

Since the effects of NaCl and Na_2SO_4 treatments on the extractable Na values in the soil were $P=0.0001<0.05$, a

statistical difference was found. The highest Na values were obtained with Na_2SO_4 treatments. The effect of B treatments on Na values was $P=0.634>0.05$, there was no statistical difference and no significant change in Na values in the soil (Figure 8).

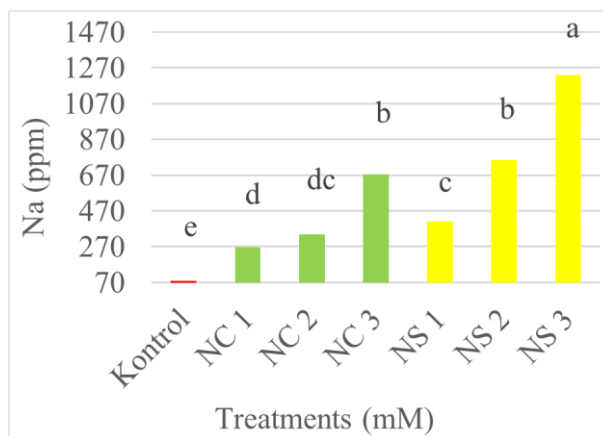


Figure 8. The effect of NaCl and Na_2SO_4 treatments on soil Na values

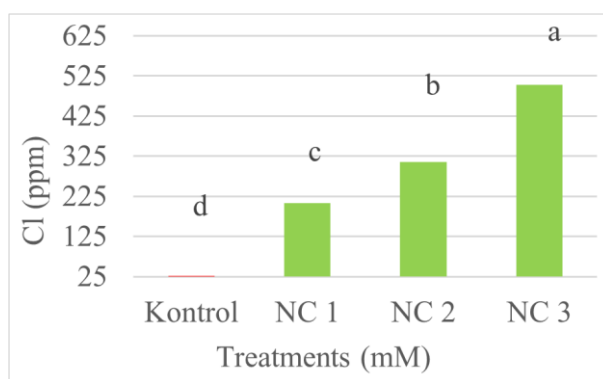


Figure 9. The effect of NaCl treatments on soil Cl values

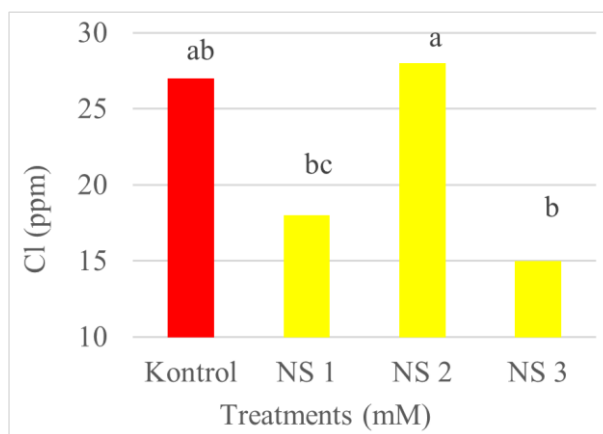


Figure 10. The effect of Na_2SO_4 treatments on soil Cl values

3.6. Soil Cl Values

The effect of NaCl treatments on soil Cl values was $P=0.0001<0.05$ and it was found statistically significant.

The Cl values increased with the increase in treatment doses. While the control was 27 ppm, it increased to 503 ppm with 150 mM NaCl treatment (Figure 9).

The effect of B treatments was $P=0.067>0.05$, and there was no statistically significant difference. There was no significant change in Cl values with treatments. The effect of Na_2SO_4 treatments was $P=0.013<0.05$ and it was found statistically significant. Moreover, decreases were observed in Cl values with treatments compared to the control (Figure 10).

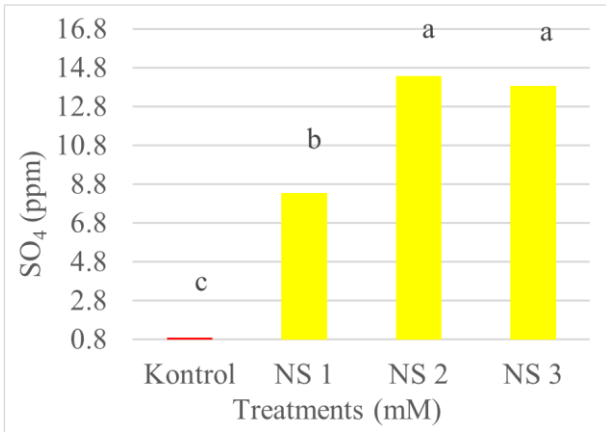


Figure 11. The effect of Na_2SO_4 treatments on soil SO_4 values

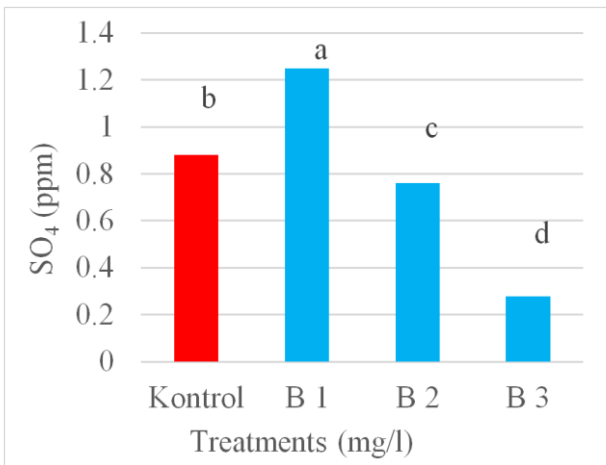


Figure 12. Effect of B treatments on soil SO_4 values

3.7. Soil SO_4 Values

The effect of Na_2SO_4 treatments on extractable SO_4 content in the soil was found to be statistically significant since $P=0.0001<0.05$. While the control value was 0.88 ppm with treatments, the highest value was obtained with 14.38 ppm in 100 mM Na_2SO_4 treatment. With the increase in dose, a decrease in SO_4 value was observed at the level of 150 mM (Figure 11). Especially in Na_2SO_4 treatments, it was understood that the salt accumulation in the leaves was removed from the leaves after a certain level. The effect of

B treatments was $P=0.0001<0.05$ and it was found significant. There was an increase in 5 mg/l compared to the control, while there was a decrease in SO_4 values with the increase in the dose (Figure 12).

Since the effect of NaCl treatments on the extractable SO_4 content in the soil was $P=0.0001<0.05$, there was a statistically significant difference. In 50 mM NaCl treatments, while there was a decrease compared to the control, the values increased above the control value with the increase in the dose (Figure 13).

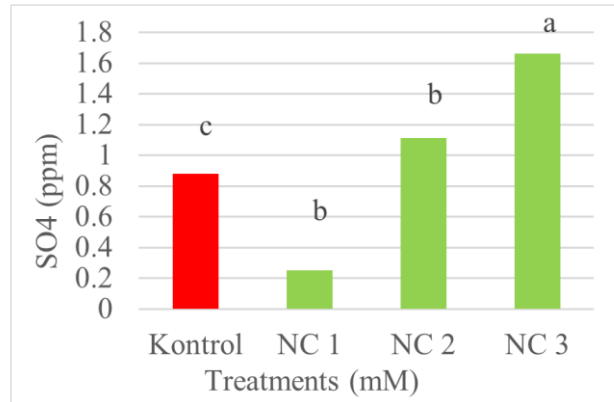


Figure 13. The effect of NaCl treatments on soil SO_4 values

3.8. Soil B Values

Since the effect of B treatments on the B content was $P=0.077>0.05$, there was no significant difference, and the values increased with the increase of the treatment doses. The effect of NaCl treatments on B content was found to be significant with $P=0.0001<0.05$. As the treatment doses increased, B values decreased. Since the effect of Na_2SO_4 treatments was $P=0.676>0.05$, no significant difference was found. As the treatment doses increased, the values decreased.

B uygulamalarında, Kontrolle göre toprakta az da olsa B seviyesi yükselmiştir fakat önemli bulunmamıştır (Figure 14). Toprağa uygulanan farklı B seviyelerine rağmen, B toksisitesi oluşmamıştır. NaCl ve Na_2SO_4 uygulamalarında ise, Kontrolle göre B değerlerinde azalmalar meydana gelmiştir (Figure 15,16).

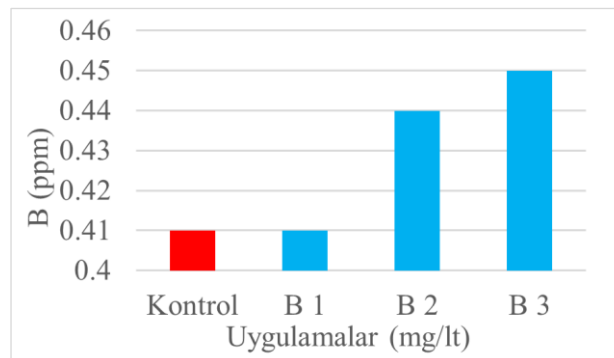


Figure 14. The effect of B treatments on soil B values

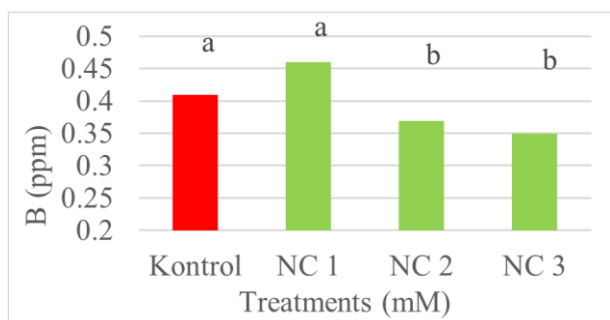


Figure 15. The effect of B treatments on soil NaCl values

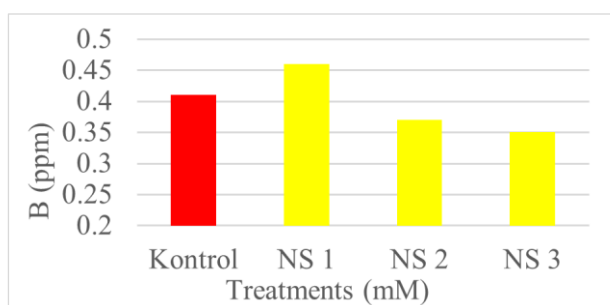


Figure 16. The effect of B treatments on soil Na₂SO₄ values

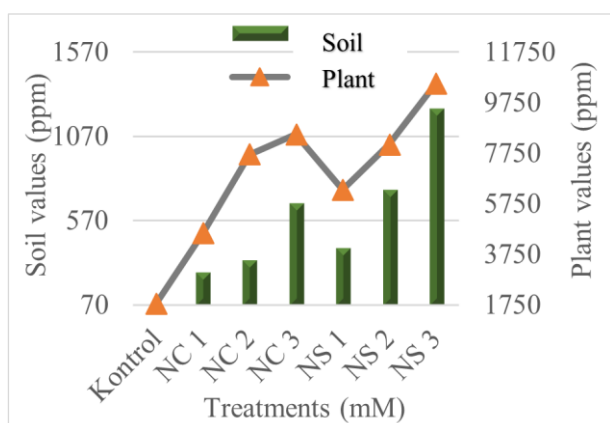


Figure 17. Na values in soil and plant

3.9. Change of Na Values in Soil and Plant

According to Figure 17, it is understood that *Limonium gmelinii* takes most of the Na applied to the soil and stores it and can retain an average of 10500 ppm Na within its body without significant damage. Moreover, the highest values were obtained in Na₂SO₄ treatments.

3.10. Change of Cl Values in Soil and Plant

More Cl was found in the plant body compared to the soil. The Cl value in the soil increased to 503 ppm, and in the plant up to 33700 ppm (Figure 18). As stated by Kocaman et al. [20], there was an increase in salt value in agricultural lands irrigated from Na₂SO₄ in the Ergene River or exposed to polluted waters as a result of floods. In addition, the Ergene River contains high amounts of

chlorine and sodium, causing a serious accumulation of sodium and chlorine in the soil. *Limonium gmelinii* plant, which has a high tolerance to the treatments, can be used for phytoremediation in areas containing intense chlorine and sodium, such as the Ergene River.

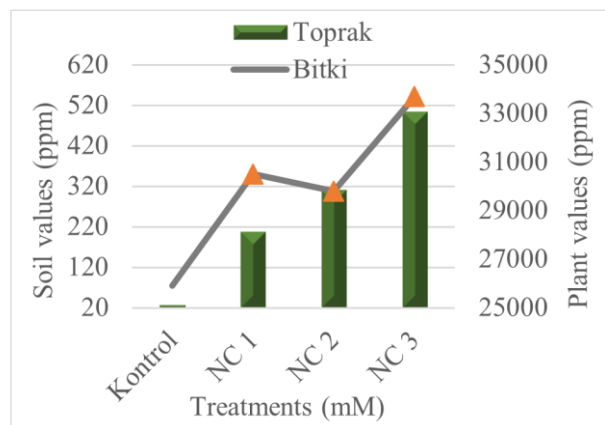


Figure 18. Soil and Plant Cl values

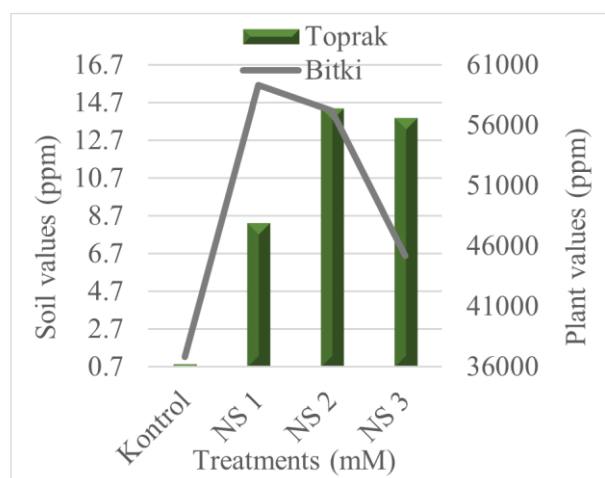


Figure 19. Soil and plant SO₄ values

3.11. Change of Soil and Plant SO₄ Values

Compared to the soil, more SO₄ was determined in the plant body. In 150 mM treatments, a decrease in SO₄ values in soil and plant was observed (Figure 19). Since *Limonium gmelinii* is in a structure that can secrete salt from its leaves through salt sacs and glands, the decrease in values despite the increase in treatment doses is attributed to this. Salt sacs consist of single epidermal cells or modified trichomes that deposit salt on the leaf surface. Salt glands, on the other hand, are stable structures composed of two or more cells that are usually embedded in the epidermis and constantly release toxic ions to the outside of the plant. A portion of the pollutants that have been gathered from the plant roots showed decay via the plant enzymes and changed their chemical form. Another portion is released in to the atmosphere via transpiration

and yet another portion accumulates on the vegetative organs of the plant showing no decay and is removed via the harvesting method. Salt glands play an important role in maintaining ion balance, contributing to the stability of osmotic pressure and increasing salinity tolerance. Salt glands also regulate the internal ionic composition of leaves, which helps prevent the dehydration of leaf cells, as well as efficient osmotic adjustments [11].



Figure 20. The appearance of salt accumulation on the leaves in Na₂SO₄ 1-2-3 treatments

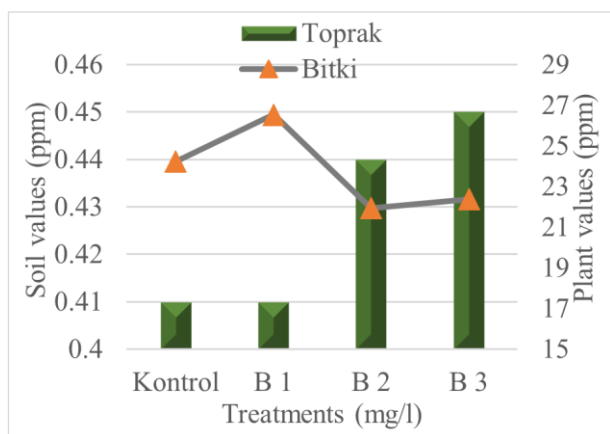


Figure 21. Soil and plant B values



Figure 22. Boron toxicity symptoms

As can be seen from the leaf images given in Figure 20, SO₄ accumulation occurred in the plant, especially on the leaf tops, compared to the soil, and the most intense accumulation was observed in the 2nd treatment. With the third treatment, it is seen that the excess salt from the leaves begins to be removed.

3.12. Soil and Plant B Values Change

As seen in Figure 21 the 5 mg/l B application on graph B1 shows a small increase in B levels. On B 2 and B 3 applications the B values carried from soil to plant have decreased. B levels showing toxicity were not found on either soil or plant. As a result B concentrations applied to the soil are carried from the soil to the plant and released in to the atmosphere due to the plant sacs and glands via the plant leaves.

According to Rozema et al [27], halophyte plants are more tolerant to boron toxicity than glycophyte plants. Halophytic plants can tolerate high boron concentrations thanks to various defense mechanisms. Although the leaves of halophytic *Atriplex littoralis*, *Matricaria maritima* and *Elymus* sp. contain high concentrations of boron, no decrease in their growth is observed. The reason for this is that they can remove high boron concentrations thanks to their salt glands. When the halophytic *Spartina anglica* is exposed to boron toxicity, it can excrete approximately 20-28% of the total boron in the stem from the plant. Besides, the halophytic *Plantago maritima* produces sorbitol, to which boron can bind effectively and thus tolerates B toxicity. The complexing of boron with sugar is thought to be a mechanism of resistance to boron toxicity and reducing toxicity. Temel [28] explained the salt tolerance mechanisms, which are developed by plants against salt stress, as “Certain halophytes do not accumulate salt ions inside the cell, but have glands that secrete salts out of the cell by accumulating them in special sacs. In other words, it contains glands that secrete salt”. Based on these views and Figure 18, it can be said that *Limonium gmelinii* is tolerant up to 15 mg/l B level, absorbs the B content applied to the soil, and then removes it from its body with special glands, and removes and tolerates B toxicity. Due to boron toxicity, symptoms such as color changes and inward curling were observed in the tips of the old leaves (Figure 22).

4. Conclusions and Suggestions

In the study, it was observed that *Limonium gmelinii* was tolerant to 150 mM NaCl, 150 mM Na₂SO₄ and 15 mg/l B applied to the soil. Furthermore, it was determined that the plant prevents toxicity in the soil by absorbing different doses of the treatments applied to the soil or removing it from the environment by taking it into its structure and throwing it out. Therefore, as a result of the data and observations obtained from the study, it was concluded that *Limonium gmelinii* can be used for phytoremediation in soils that are exposed to NaCl, Na₂SO₄ and B toxicity.

In the province of Antalya, where the research was carried out, it is known that *Limonium gmelinii* is naturally grown as a result of field observations. By cultivating *Limonium gmelinii* in open fields on soils with salinity problems and B toxicity, including Antalya Province, these

areas can be transformed into agricultural usable areas with a more economical and aesthetic appearance, without being exposed to any chemicals or washing processes. It will be very beneficial to carry out studies on this plant, which can be grown in Turkey, to contribute to the country's economy.

The fact that the phytoremediation technique is environmentally friendly, low in cost and easily applicable in practice, and that the obtained plants can be used in many areas such as food, feed, green manure and fuel, has increased its importance compared to other methods. Considering that these plants do not create competition when used together with cultivated plants, it is seen that they have a high potential.

The lack of literature can be eliminated by conducting studies to determine other usage areas (cosmetics, medicine, detergent, feed, fertilizer, etc.) of *Limonium gmelinii*, which can be used for the improvement of soils with salinity problems and B toxicity. With the cultivation and dissemination of the plant, a profit can be made in terms of the ornamental plants' sector. Besides, the harvested plants can be evaluated in different fields by processing. Seed production of this plant, which is not sold in Turkey, can be provided. Most importantly, it can contribute to the country's economy by making the unusable lands usable for agriculture.

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