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Effect of Vermicompost on Macro and Micro Nutrients of Lettuce (*Lactuca Sativa* Var. *Crispa*) Under Salt Stress Conditions

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ABSTRACT

This study was conducted in order to determine the effect of vermicompost (V) on macro and micro nutrients of lettuce (*Lactuca sativa* Var. *crispa*) exposed to salt stress (SS). V doses; 0 (V0), 2.5% (V1) and 5% (V2) (w/w) and salt stress levels; control (SS0) (0 dS m^{-1} NaCl), medium salt stress (SS4) (4 dS m^{-1} NaCl), severe salt stress (SS8) (8 dS m^{-1} NaCl) were used. In order to make evaluation in terms of the nutrients, plants were kept under controlled conditions (relative humidity 50-55%, daytime/night time temperature 24/20 °C) in the greenhouse for 46 days (May 24 and July 10, 2017). While the medium and severe salt stress decreased the P, K, Mg, Fe, Mn and Zn concentrations of plants significantly, compared to the control, it caused increase in N and Na concentration. While Na decreased due to the V, other mineral element concentrations increased significantly and these increases were found more effective in 5% V application. The effect of SS x V interaction was statistically significant in terms of N, P, Mg, Na, Fe, Mn and Zn, whereas it was found insignificant for K, Ca and Cu. It was shown that in lettuce growing, V applications in areas with salinity problems could contribute to reducing the toxic effects of salinity on the plant and improving the imbalance in nutrient intake.

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Tuz Stresi Altında Vermikompost Uygulamasının Kıvırcık Salatada (*Lactuca Sativa* Var. *Crispa*) Makro ve Mikro Element İçerikleri Üzerine Etkisi

ÖZET

Bu çalışma, tuz stresine (SS) maruz kalmış kıvırcık salata bitkisinin (Lactuca sativa Var. crispa) makro ve mikro besin içerikleri üzerine vermikompostun (V), etkisini belirlemek amacıyla yapılmıştır. V'un dozları ile; 0 (V0), %2.5 (V1) ve %5 (V2) (w/w), tuz stresi seviyeleri; kontrol (SS0) (0 dS m-1 NaCl), orta derecede tuz stresi (SS4) (4 dS m-1 NaCl), şiddetli tuz stresi (SS8) (8 dS m-1 NaCl) kullanılmıştır. Besin içerikleri bakımından değerlendirmek amacıyla bitkiler 46 gün (24 Mayıs-10 Temmuz 2017) boyunca serada kontrollü koşullar altında tutulmuştur. Orta ve şiddetli tuz stresi bitkilerin P, K, Mg, Fe, Mn ve Zn konsantrasyonlarını kontrole göre önemli seviyelerde azaltırken, N ve Na konsantrasyonlarında ise artışa neden olmuştur. V uygulamaları ile Na azalırken diğer mineral element içerikleri önemli ölçüde artmış ve bu artışlar %5 V uygulamasında daha etkili bulunmuştur. SS x V interaksiyonunun etkisi N, P, Mg, Na, Fe, Mn ve Zn bakımından istatistiksel olarak önemli bulunurken, K, Ca ve Cu için önemsiz olmuştur. Tuzluluk probleminin bulunduğu alanlarda V uygulamalarının kıvırcık salata yetiştiriciliğinde, tuzluluğun bitki üzerine olan toksik etkisini azaltmaya ve besin maddelerinin alımındaki dengesizliği iyileştirmeye katkıda bulunabildiğini göstermiştir.

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INTRODUCTION

Salinity occurs as a result of ascending of the soluble salt, which merges into underground water by being washed especially in dry and semi-dry climates, to the soil surface via capillary with high ground water and the accumulation of it on the soil surface due to the evaporation of the water. The salt stress is, on the other hand, defined as the availability of different salts in soil or water in concentrations that prevent plant growth and reduce the efficiency of the plant. As the salt concentration increases in the soil, the water intake of the plant from the soil becomes difficult and physiological and biochemical changes occur in the plant (Munns and Tester, 2008). The decrease in osmotic potential of the soil solution, ion toxicity, and the imbalance in intake of nutrients affect plant growth adversely (Parvaiz and Satyawati, 2008). Because of the limited sweating rates, impaired active transport, and membrane permeability due to the effect of physiological drought caused by salinity, both the nutrient intake of the roots and transportation of them from roots to shoots are reduced (Alam,1999). In addition to this, Na^+, Ca^{2+}, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^- and NO_3^-, which are excessive in salty soil conditions, cause specific ion toxicities (Na^+ and Cl^-), and as a result of this, ionic imbalances that affect the biophysical and/or metabolic components of plant growth occur (Hu and Schmidhalter, 1999). The salt stress causes adverse effects on the growth and development of the plant with the increase of the amount of NaCl application and other soluble salts in the soil. The increase of the salt concentration in soil solution decreases the osmotic potential of plant cells and leads to occurring of a series of reactions in plants (Parida and Das, 2005). Therefore, depending on its intensity and duration, the salt affects many biological events such as growth, development, germination, cell division, and photosynthesis in plants (Bressan, 2008), and the salinity limits the quality of the product by affecting the plant growth and nutrient intake (Koca, 2007).

In reducing the negative impact of salinity on plant growth, the use of soil regulators having organic fertilizer characteristic take place among the important cultural practices. Organic matters increase the micronutrient concentration (Demir and Işık, 2019a,b; Demir et al., 2019a) and macronutrient of the soil and by improving its structure, it contributes to the increase of soil fertility and quality (Ayyobi et al., 2014). Because of these characteristics, the use of organic fertilizers has become a common cultural method used in the improvement of salted soil in recent years (Lakhdar et al., 2009). Vermicompost is defined as a soil regulator and organic fertilizer that is derived from the conversion of various organic wastes into humus-like substances by worms and that is rich in terms of the enzyme, humic and fulvic acid (Arancon et al., 2003). It has been reported in the literature that in addition to that vermicompost has a positive effect on plant growth and soil improvement, it has also effect on the supporting of the plant stress tolerance by reducing the adverse effects of toxic elements in the salt stress conditions and by creating an anti-stress effect (Ayyobi et al., 2014; Bidabadi et al., 2017; Jabeen and Ahmad, 2017). For ATP, the formation of sugars and nucleic acids, photosynthesis, regulation of enzymes and transport of carbohydrates, plants need phosphorus when it is necessary. It is also necessary for the formation of DNA, which determines the genetic characteristics of the plant. Phosphorus plays an important role in cell division and the formation of flower and fruits (McCauley et al., 2009). K, one of the essential elements for growth and development, plays a role in maintaining osmotic balance, regulation of enzyme activity, protein synthesis, neutralization of negatively charged proteins and movement of stomas (Wu et al., 1996). Not only K and Na concentration but also K/Na ratio can be used as a parameter that gives clues about the physiological response of plants to the salt stress (de Lacerda et al., 2005). One of the essential elements for growth and development is Ca ion. Calcium is supposed to be directly involved in Na exclusion and retention mechanisms regulating Na transport (Melgar et al., 2006). By releasing the Ca, which are available as bounded in the internal membrane structures, high Na concentration causes the internal Ca stores to empty and causes increasing of free Ca in the cell (Yokoi et al., 2002). In saline and sodic soils, the solubility of micronutrients is particularly low, and plants grown in these soils often experience deficiencies in these elements (Page et al., 1990). The iron element plays a role in respiration and photosynthesis reactions in plants and ensures catalyze of many biochemical reactions by activating the enzymes such as catalase, peroxidase and cytochrome oxidase in plants. Although it is not available in the structure of the chlorophyll, in iron deficiency, chlorophyll production decreases and plant growth takes place slowly. It is effective on the protein mechanism in plant (McCauley et al., 2009). Lettuce (*Lactuca sativa* var. *Crispa*) is a type of cool-weather vegetable that is sensitive to salt stress (Qin et al., 2013). Salt stress downgrades the plant growth by adversely affecting the plant physiology of the lettuce and decreases productivity significantly (Çamoğlu and Demirel, 2015). Salinity has been shown to reduce seed germination, fresh and dry weight of shoot, and root weight of lettuce both by ionic and osmotic effects (Tarakcioglu and Inal, 2002). For this reason, in the places where lettuce is grown and the salinity problem is present, vermicompost can contribute to reducing the toxic effect of salinity on the plant and improving the imbalance in the intake of nutrients. The purpose of this study is to determination the effect of vermicompost on macro and micro nutrients contents of lettuce grown under salt stress.

MATERIAL and METHOD

Plant Material and Applications

The study was conducted under controlled greenhouse conditions at Soil Fertilizer and Water Resources Central Research Institute between March 24 and July 10, 2017 (relative humidity: 50-55%, daytime/night time temperature: 24/20 °C). The lettuce seeds (*Lactuca sativa* var. *Crisp*a) were planted into the environment containing the 1:1 ratio of vermiculite and perlite (March 24). The seedlings that became to have 3-4 real leaves were planted in 7 L pots (diameter: 25 cm, depth: 22 cm) in which there were sandy clay-loam soil and vermicompost (V) in different levels (May 10). The chemical properties of the used soil and V are given in Table 1. In this study, 0% (control), 2.5% V, and 5% V (w/w) doses of the V were included and V was not added to the control pots. Two weeks after the transfer of seedlings to the pots, salt stress treatments were started (May 24). Plants were irrigated with tap water (EC; 0.20 - 0.70 dS m^{-1}, pH; 6.8 - 7.10) at field capacity level until salt stress applications started. For salt stress, throughout the cultivation period, salty water whose electrical conductivity (EC) was at 4 and 8 dS m^{-1} levels was given to the plants to which salt treatment would be performed. NaCl stock solution was used in the preparation of the salt water. While the plants were irrigated with irrigation water containing NaCl throughout the growing period and in free drainage conditions (field capacity + 20% washing water), only tap water was given to the plants that were subject of the control. The plants were grown under these conditions for 46 days (May 24 and July 10). At the end of this period, they were harvested and samples ömwere taken for the analyses of mineral elements.

Table 1. Some properties of soil and vermicompost used in the experiment
Tablo 1. Denemede kullanılan toprak ve vermikompostun bazı özellikleri

Properties	Soil	Properties	Vermicompost
Soil texture	Sandy clay loam (SCL)		
pH (1:1)	7.75	Moisture (%)	21.6
EC (dS m^{-1})	1.59	EC (dS m^{-1})	6.5
OM (%)	0.31	Organic matter (%)	65.5
P_2O_5 (kg da^{-1})	3.85	Total P (mg kg^{-1})	7259
K_2O (kg da^{-1})	71.70	Water soluble K (mg kg^{-1})	12810
Ca (mg kg^{-1})	22.9	Ca (mg kg^{-1})	25090
Mg (mg kg^{-1})	0.75	Mg (mg kg^{-1})	6559
Fe (mg kg^{-1})	1.01	Fe (mg kg^{-1})	2065
Mn (mg kg^{-1})	2.27	Mn (mg kg^{-1})	272
Zn (mg kg^{-1})	0.63	Zn (mg kg^{-1})	216

Analyses of Mineral Elements

The harvested plants were washed with tap water and pure water, respectively, then dried at 65 °C in the drying-oven to constant weight and then grinded (Kacar, 1972). In dried and grinded leaf samples, the concentration of N was determined by reading in Leco TruSpec- CHN tool according to the Dumas method (Kacar and Inal, 2008). Result of macro and micro elements analysis (P, K, Ca, Fe, Zn, Mn, Cu) 250 mg of leaf sample was first digested with nitric acid (HNO_3) in microwave device, then the samples were transferred to 50 ml of erlenmeyer flasks and deionized water was added on them and then they were filtered out by filter paper (Kacar and Inal, 2008). In the obtained extracts, the total K was determined by reading in Jenway PFP 7 Flamefotometer. Total phosphorus was determined in Shimadzu UV-160 Spectrophotometer according to vanadomolybdophosphoric yellow color method. 5 ml solution of the taken from this plant solution was placed in a 50 ml measuring flask. Deionized water was added to the measuring flask until the solution volume was about 40 ml. Finally, Barton solution (5 ml) was added with shaking. The flask was completed to the degree with distilled water and shaken. After the addition of Barton solution (10 minutes), the light absorption of the colored solution was determined in the spectrophotometer adjusted at 430 nm wavelength (Kacar and Inal, 2008). Ca, Fe, Zn, Mn, Cu concentrations were determined by reading in Varian 720-ES ICP-OES (Inductively Coupled Plasma-Optical Emission Spectrometry) (Kacar and Inal, 2008). In determining the Fe, Zn, Mn, Cu, Na, Ca and Mg concentrations used ICP-OES, at wavelengths: Fe: 238.204 nm, Zn: 213.857 nm, Mn: 257.610 nm, Cu: 327.393 nm, Na: 588.995 nm, Ca: 317.933 nm and Mg: 279.806 nm (Kacar and Inal, 2008).

Statistical analysis

Experimental results were subjected to statistical analyses with SPSS. Data were subjected to ANOVA. Correlation analyses were performed to express the relationships between experimental parameters (Yurtsever, 2011).

RESULTS and DISCUSSION

The effects of vermicompost (V) treatments on shoot dry weight of lettuce (*Lactuca Sativa* Var. *Crispa*) under salt stress are given in Figure 1. There were significant effects of V treatments and salt levels on shoot dry weight of lettuce (*Lactuca Sativa* Var. *Crispa*) ($p < 0.01$). However, V x salt levels interactions did not have significant effects on the shoot dry weight of lettuce (Table 4). The high salt level (8 dS m^{-1}) had the lowest shoot dry weight (10.86 g $plant^{-1}$), whereas the control treatment (without salt stress) had the highest shoot dry weight (16.60 g $plant^{-1}$) (Figure 1a). As compared to control (without salt stress), the 4 and 8 dS m^{-1} salt levels decreased the shoot dry weight of lettuce by 25.4% and 52.9%, respectively. Al-Maskari et al. (2010) found that shoot dry weight was significantly affected in response to salinity stress but insignificant differences were observed between 0 mM and 50 mM salinity treatments. The highest growth was observed in 0 mM salt, while it was lowest at 100 mM salinity stress. Similarly, Ekinci et al. (2012) found that shoot dry weight were decreased by 60% in response to 100 mM NaCl compared with the untreated control. Such stimulation in dry matter production under the influence of salinity might be due to the accumulation of inorganic ions and organic solutes for osmotic adaptation while a decrease in dry matter content at the highest salinity levels might be due to the inhibition in hydrolysis of reserved foods and their translocation to the growing shoots (Xu et al., 2008). Lettuce responded to salt stress with the highest sensitivity, which showed as a significant reduction of dry weight and even lower concentrations of salt affected membrane stability (Hniličková et al., 2019). The findings were similar to those reported by Bar-Yosef et al. (2005). Present findings of the shoot dry weight well comply with the findings of those earlier studies.

The 2.5% V treatment had the highest shoot dry weight (16.07 g $plant^{-1}$), whereas the control treatment (without V) had the lowest shoot dry weight (9.11 g $plant^{-1}$) (Figure 1b). As compared to control (without V), the 2.5% V and 5% V treatments increased the shoot dry weight of lettuce by 76.4% and 74.6%, respectively. Stancheva and Mitova (2002) found a significant increase in total dry weight for lettuce in response to vermicompost applications. Similarly, a study by Edwards (1995) revealed that vermicompost treatments increases plant dry biomass. This correlates to results observed where increase vermicompost was directly proportional to biomass assimilated. 300 kg da^{-1} vermicompost treatments were found as the highest (6.39 kg m^{-2}) whereas control plots were found as the lowest yield (4.75 kg m^{-2}) As compared to control, the 300 kg da^{-1}vermicompost treatments increased yield of lettuce by 34.53% (Durak et al., 2017). Recent studies showed that increasing impact of vermicompost on plant growth is caused by its increasing humic acid content (Atiyeh et al., 2000a; Atiyeh et al., 2000b). Plant growth regulators and symbiotic microorganisms (Atiyeh et al., 2002; Arancon et al, 2004), growth hormones and other hormones are absorbed by humic acid during the process of vermicompost production (Edwards et al., 2006). Supplementation of soil with vermicompost develops plant growth by increasing humic acid content and consequently increases plant growth hormones and other beneficial symbiotic microorganisms. Besides, it helps availability of plant nutrients by improving soil structure and microorganism activity and also this way increases plant growth (Durak et al., 2017).

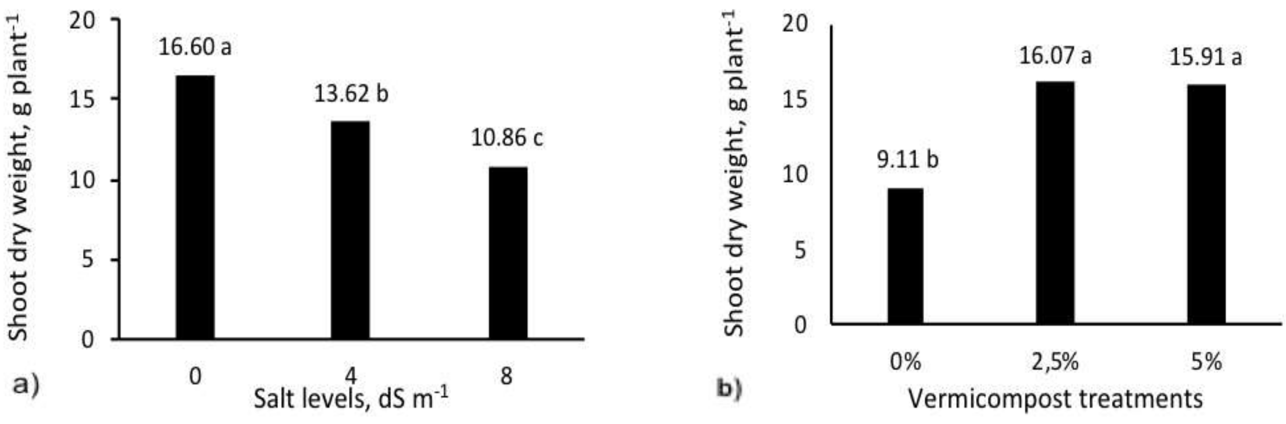

Figure 1. Effects of salt levels (a) and vermicompost (V) treatments (b) on shoot dry weight of lettuce (*Lactuca Sativa* Var. *Crispa*)

Şekil 1. Kıvırcık salata bitkisinin (Lactuca Sativa Var. Crispa) yeşil aksam kuru ağırlığı üzerine tuz seviyeleri ve vermikompost uygulamalarının etkisi

For vermicompost (V) applications under salt stress, the obtained data in terms of N, P, K, Ca, Mg, Na, Fe, Mn, Zn and Cu concentrations of the lettuce plant were evaluated. As a result of the analysis of variance, the values for each of the examined parameter were evaluated separately on the basis of Salt stress (SS) x Vermicompost (V) interaction. Whereas the effect of SS x V interaction was found to be statistically significant in terms of N, P, Mg, Na, Fe, Mn and Zn concentrations, any significant effect of it was not observed for K, Ca and Cu concentrations (Table 4 and 5). Salinity dominated by Na and Cl ions decreased the concentration of essential macro and microelements in several vegetable crops (Grattan and Grieve, 1999; Yildirim et al., 2006). High concentrations of NaCl in the soil solution may disorder nutrient-ion activities, causing plants to be susceptible to osmotic and specific ion injury as well as to nutritional disorders that result in reduced yield and quality (Grattan and Grieve, 1999). In this study, vermicompost treatments ameliorated the deleterious effects of salinity stress on plant growth and improved nutrient uptake of lettuce under salinity stress.

The results of the study showed that the salt stress significantly increased the N concentration in plant leaves compared to the control (Table 2). Belliturk et al. (2017) found that the total N correlation coefficient of cow manure was highest (0.736) and vermicompost had the lowest total nitrogen (0.14). In addition, they determined that vermicompost additions encourage earlier germination by as much as one week. This may be due to the higher nutrient availability of vermicompost earlier in the application process. This indicates that vermicompost would have a high use value when beginning the growing season earlier in a priority (Belliturk et al., 2017).

Table 2. Effect of salt stress x vermicompost interaction on N, P, K, Ca, K, Mg and Na concentrations of lettuce (*Lactuca Sativa* Var. *Crispa*)

Tablo 2. Kıvırcık salata bitkisinin ((Lactuca Sativa Var. Crispa) N, P, K, Ca, K, Mg ve Na konsantrasyonları üzerine tuz stresi x vermikompost interaksiyonunun etkisi

SS (dS m^{-1})	V (%)	SDW (g $plant^{-1}$)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)
0	0	11.56	2.43 bc	0.22 e	2.64	0.91	0.34 a	0.58 c
	2.5	18.64	2.35 bc	0.27 b	2.82	1.07	0.33 ab	0.59 c
	5	19.61	2.62 b	0.25 bc	2.79	0.97	0.34 a	0.37 d
4	0	8.92	1.62 d	0.24 cd	2.53	0.97	0.32 bc	0.84 b
	2.5	16.22	2.41 bc	0.29 a	2.62	0.98	0.32 bc	0.87 b
	5	15.72	2.39 bc	0.26 b	2.86	0.99	0.31 c	0.88 b
8	0	6.84	2.18 c	0.16 f	2.32	0.98	0.26 d	1.21 a
	2.5	13.35	2.39 bc	0.23 de	2.45	0.96	0.27 d	1.19 a
	5	12.40	2.96 a	0.26 b	2.74	1.09	0.33 ab	1.18 a
Lsd %5		-	0.33	0.02	-	-	0.02	0.10

The difference between mean values of different letters in the same column is significant ($p \leq 0.05$). SS: Salt Stress, V: Vermicompost, SDW: Shoot dry weight.

Table 3. Effect of the salt stress x vermicompost interaction on K/Na, Ca/Na, Fe, Mn, Zn and Cu concentrations

Tablo 3. K/Na, Ca/Na, Fe, Mn, Zn ve Cu konsantrasyonları üzerine tuz stresi x vermikompost interaksiyonunun etkisi

SS (dS m^{-1})	V (%)	K/Na	Ca/Na	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})
0	0	4.56 b	1.57 bc	702 b	140 a	48.3 cd	17.0
	2.5	4.86 b	1.83 b	741 ab	142 a	63.4 a	16.7
	5	7.74 a	2.72 a	778 a	143 a	52.6 bc	16.4
4	0	3.03 cd	1.17 cd	350 e	139 a	34.0 e	14.2
	2.5	3.01 cd	1.13 d	445 d	112 bc	52.6 bc	14.7
	5	3.25 c	1.12 d	655 c	121 b	48.5 bcd	15.3
8	0	1.92 e	0.81 d	275 f	125 b	32.8 e	17.9
	2.5	2.06 e	0.81 d	331 e	100 c	43.4 d	15.8
	5	2.33 de	0.93 d	405 d	101 c	56.6 ab	16.3
Lsd %5		0.77	0.40	43.45	13.62	8.07	-

In the same column, the difference between the averages taking different letters is significant ($p \leq 0.05$). SS: salt stress, V: Vermicompost

Table 4. Results of variance analysis for N, P, K, Ca and Mg
Tablo 4. N, P, K, Ca ve Mg varyans analiz sonuçları

Variation parameters	*Sd*	SDW	N	P	K	Ca	Mg
SS	2	**	**	**	*	ns	**
V	2	**	**	**	*	ns	*
SS x V	4	ns	**	**	ns	ns	**
Error	18	5.81	0.04	0.00	0.03	0.01	5.00
CV (%)		17.60	7.99	6.64	6.96	7.80	0.00

ns; not significant, ** significant at 1% level, * significant at 5% level. SS: Salt stress, V: vermicompost, SDW: Shoot dry weight, CV: coefficient of variation.

Table 5. Results of variance analysis for Fe, Mn, Zn, Cu, Na, K/Na and Ca/Na
Tablo 5. Fe, Mn, Zn, Cu, Na, K/Na ve Ca/Na varyans analiz sonuçları

Variation parameters	*Sd*	Na	K/Na	Ca/Na	Fe	Mn	Zn	Cu
SS	2	**	**	**	**	**	**	**
V	2	*	**	**	**	**	**	ns
SS x V	4	*	**	**	**	*	**	ns
Error	18	0.01	0.20	0.06	641.68	63.01	22.14	1.093
CV (%)		7.23	12.37	17.55	4.87	6.37	9.80	6.52

ns; not significant, ** significant at 1% level, * significant at 5% level. SS: Salt stress, V: vermicompost, CV: coefficient of variation.

Vermicompost (Demir, 2019), organic fertilizer/ manure (Candemir and Gülser, 2010; Demir and Gülser, 2015; Demir et al., 2019b; Demir and Işık, 2019c,d) supplementation to soils as a source of organic matter and nutrients improved soil fertility in a short period of time. Azarmi et al. (2008) found that the application of vermicompost improved the crop quality and nutritional concentration, organic carbon, N, P, K, Ca, Zn, and Mn. Kmetova and Kovacik (2013) who also observed 10-fold higher total N concentration in vermicompost compared to soil. As well as triggering the closure of the stomas, NaCl affects the mobility of nitrogen into the leaves by causing changes in the structure of proteins in chloroplast thylakoids (Ferroni et al., 2007). In addition to this, V applications under salt stress significantly increased the N concentration of the plants. As the V dose increases, more N has accumulated in the leaves. The highest N value under salt stress occurred in SS8 x V2 interaction (2.96%). The N concentration (2.20%) of the V used in the experiment is thought to be associated with the increase in the N concentration of the lettuce plant.

The salt stress led to a significant decrease in P concentration compared to the control, V application caused an increase depending on the dose increase (Table 2). The highest P concentration under salt stress was determined in SS4 x V1 interaction (0.29%). In addition to reducing the water potential in the plant, NaCl salt used in the experiment may have also caused the loss of P in the plant by disrupting the ion balance in the cell (Parida and Das, 2005). Passive nutrient uptake is relevant to water intake, and any decrease in water availability reduces the uptake of plant nutrients. Additionally, an imbalance in the composition of saline soil solution can cause an excessive or insufficient uptake of some ions (Ghafoor et al., 2004). In addition, it has been reported in some studies that V application increase resist stress by increasing P mineralization and intake of it by the plant (Hashemimajd et al., 2004; Arancon et al., 2006). It is known that when organic matter is added to the soil, P mineralization increases. Similarly, as a result of the conducted studies, it was determined that the P mineralization in the soil increased with vermicompost application (Uma and Malathi, 2009).

While the salt stress caused a significant decrease in K concentration compared to the control, V application led to the increase (Table 2). The highest K concentration under salt stress was determined in SS4 X V2 interaction (2.86%). It is thought that the K concentration of vermicompost (1.50%) used in the experiment is effective in the occurring of the increases in K concentrations of the lettuce plant. The excess salt taken into the plant is competing with the intake of other nutrient ions, especially K. In general, salinity in many plants causes increase in Na levels and K causes decrease in Mg levels (Parida and Das, 2005; Kusvuran et al., 2008). Related to the salt stress, it has been identified that K concentration decreases as the Na concentration of corn leaves and roots increases (Azevedo Neto et al., 2004). Increased Na^+ content along with increasing salt concentrations were reported for lettuce (Ünlükara et al., 2008), New Zealand spinach Yousif et al. (2010) and purslane (Uddin et al., 2012). K^+ content due to salt stress in comparison with the control group decreased in the species (Hniličková et al., 2019).

The salt stress led to a significant increase in Na concentration compared to the control (Table 2). The highest Na concentration under the salt stress was determined in SS8 X V0 interaction (1.21%). Therefore, high K/Na and (K+Ca+Mg)/Na ratios of plant leaves can be considered as a key indicator reflecting the adaptation levels of plants to the salt stress. Being functional of many cytosolic enzymes in plant cells depends on a specific K-Na balance (Mahajan et al., 2005). In the outside environment, while entering of Na to the cell increases as a result of increasing of Na, intake of K to the cell decreases; depending on this, the K-Na balance deteriorates. In this study, it was observed that the ratio of K/Na ion in the plant decreased under salt stress, but this ratio increased with the increase in dosage due to the V application. The reason for this is that Na competes with K for the areas where K will be bounded (Tester and Davenport, 2003). In the conditions of salt stress, at high concentration, Na accumulates in the apoplast. The accumulated Na can prevent cell wall to perform its basic functions by disrupting Ionic connections of structural elements such as pectin or by adversely affecting apoplastic enzymes (Rengel, 1992).

In this study, although Ca concentration is not significant statistically, V applications under salt stress conditions caused an increase in Ca concentration of the lettuce compared to the control (Table 2). In addition, it is thought that NaCl accumulation causes the depolymerization of microtubules and prevent the formation of the spindle apparatus in cell division (Rengel, 1992). By changing place with Ca in the cell membrane, Na ensure decreasing of the Ca/Na ion ratio in apoplast part of the membrane. In this study, it was observed that the Ca/Na ion ratio in the plant decreased under salt stress, but this ratio was increased by increasing the concentration of dose with V application. In this case, the physiological and functional structure of the membrane deteriorates and the Ca balance of the cell is affected (Yokoi et al., 2002).

Medium and severe salt stress decreased the Fe, Mn and Zn concentrations of plants significantly compared to the control (Table 3). Under salt stress, the highest Fe concentration was identified at SS0 x V2 interactions (778.31 mg kg^{-1}) (Table 3). As reported by the relationships between salinity and micronutrients are complex and differences can be attributed to plant type and tissue, salinity level and composition, micronutrient concentration in the medium, growing conditions and the duration of study (Grattan and Grieve, 1999). Some of the possible reasons above-mentioned are beyond the scope of this study. In addition to this, V applications significantly increased the Fe, Mn and Zn concentrations of the plants under salt stress. V ensured the enrichment of the soil in terms of Fe and Mn, and helped the usefulness of the nutrient elements by the secretion of the plant growth regulators in plant rhizosphere thanks to the beneficial microorganisms it contains (Rangarajan et al., 2008). Thus, it significantly increased the Fe and Mn intake of plants especially under medium stress. It has been reported in the literature that V increased the Fe and Mn coverage of the soil (Azarmi et al., 2008). While Zn plays an important role in carbohydrate metabolism, protein synthesis, oxen metabolism and enzyme activation, Cu takes charge in plants as the cofactor of many enzymes and the regulator of proteins (Marschner, 1995). The highest concentration of Mn under salt stress was determined in SS0 X V2 interaction and the highest Zn concentration was determined in SS0 X V1 interaction (63.43 mg kg^{-1}) (Table 3). It has been found that as a result of increasing sodicity, the zinc concentration in shoot tissue decreases (Mehrotra et al., 1986). On the other hand, in the Cu concentration, the salt stress x vermicompost interaction was not statistically significant (Table 3). V applications increased significantly the Fe, Mn and Zn concentrations of the plant, which was under severe salt stress, at the dose of 5% at most. Similar results have been also reported by Abbaspour et al. (2012) and Hu and Schmidhalter (2005). Leaf concentration of Mg, Fe, Zn, and Cu was increased and Na concentration was lower with vermicompost, which can be an advantage for using this product over traditional compost (Hernandez et al., 2010). Vermicompost improved nutritional quality of some vegetables (Gutiérrez-Miceli et al., 2007), strawberries (Singh et al., 2008), lettuce (Coria-Cayupan et al., 2009) and Chinese cabbage (Wang et al., 2010). V applications probably increased the biological availability and transport of Zn and Cu by the plant and encouraged plant growth (Kıran, 2019). This situation was also emphasized by the previous research (Pant et al., 2009; Filek, 2012).

For the V applications under salt stress, correlation analysis was used to evaluate the relationship between the macro and micro nutrient elements of the lettuce plant. The relationships between all studied mineral elements were evaluated in terms of statistical significance levels by depending on the error limit of $p \leq 0.01$ and $p \leq 0.05$. Positive correlations were found between K/Na and Ca/Na (0.98**), K/Na and Fe (0.85***), Ca/Na and Fe (0.82**), Fe (0.81**), Zn and K (0.80***), mg and K (0.76**), Zn and p (0.72*), and Zn and N (0.68*). Negative correlations were found between K/Na and Na (-0.93**), Ca/Na and Na (-0.92***), Na and Fe (-0.88**), Na and Mn (-0.81**), and Na and MG (-0.73*) (Table 6). On the other hand, the effects of applications on the relationship between other mineral elements of the lettuce plant were found insignificant. The relations between salinity and mineral nutrition of plants are equally complex and a full understanding of these interactions would require a multidisciplinary team of equal strength and diversity. Salinity can cause a combination of complex interactions affecting plant metabolism or susceptibility to injury. In several studies it has been shown that salinity increases the internal requirement for a particular nutrient (Grattan and Grieve, 1999).

Table 6. The relationships between the vermicompost applications and macro and micro nutrients of the lettuce (*Lactuca Sativa Var. Crispa*) plant under salt stress

Tablo 6. Tuz stresi altında kıvırcık salata bitkisinin (Lactuca Sativa Var. Crispa) makro ve mikro besin elementleri ve vermikompost uygulamaları arasındaki ilişkiler

		1	2	3	4	5	6	7	8	9	10	11	12
1	N	1.00											
2	P	0.30	1.00										
3	K	0.45	0.71	1.00									
4	Ca	0.38	0.34	0.38	1.00								
5	Mg	0.32	0.61	0.76**	0.17	1.00							
6	Fe	0.31	0.38	0.81**	-0.04	0.70*	1.00						
7	Cu	0.37	-0.63*	-0.17	0.08	-0.18	0.16	1.00					
8	Mn	-0.42	-0.14	0.24	-0.26	0.43	0.61	0.17	1.00				
9	Zn	0.68*	0.72*	0.80**	0.54	0.64*	0.66*	0.07	0.02	1.00			
10	Na	0.01	-0.33	-0.59	0.24	-0.73*	-0.88**	0.01	-0.81**	-0.43	1.00		
11	K/Na	0.19	0.26	0.58	-0.16	0.66*	0.85**	0.13	0.71*	0.44	-0.93**	1.00	
12	Ca/Na	0.17	0.25	0.55	-0.11	0.65*	0.82**	0.15	0.71*	0.45	-0.92**	0.98**	1.00

CONCLUSION

In this greenhouse experiment, the effects of vermicompost (V) application on the macro and micro nutrients of the lettuce plant under salt stress conditions were investigated. The present study demonstrates salinity stress induced lower plant growth. The high salt level had the lowest shoot dry weight, whereas the control treatment (without salt stress) had the highest shoot dry weight. The 2.5% V treatment had the highest shoot dry weight, whereas the control treatment (without V) had the lowest shoot dry weight. Present findings revealed that use of vermicompost was likely to be helpful for alleviating salinity in salt-affected lands. Whereas the salt stress decreased the P, K, Mg, Fe, Mn and Zn concentrations of plants significantly compared to the control, it led to an increase in the concentrations of N and Na. Increased vermicompost applications under salt stress affected the mineral concentrations (N, P, K, Ca, Mg, Fe, Mn, and Zn) of the lettuce plant positively in terms of statistically. The macro and micro nutrients of the lettuce plant were negatively affected due to the increase of Na ion in the plants subjected to salt stress. It is thought that the high mineral element concentration of vermicompost used in the experiment is effective on the enrichment of the lettuce plant under salt stress in terms of macro and micro nutrient elements, the increasing of the usefulness of nutrient elements and the tolerance of plants against the stress. The results of this study showed that V treatments improved the macro and micro nutrients of the lettuce plant under salt stress conditions in greenhouse conditions, but longer term studies in field conditions are needed to evaluate the long-term effects. Therefore, it is not practical to perform economic analysis in pot conditions, but it will be more accurate to perform economic analysis after field conditions. It was shown that the vermicompost applications in areas where the lettuce cultivation was performed and salinity problems were present could contribute to the reducing the toxic effects of salinity on the plant and to the improving the imbalance in the intake of nutrients.

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Statement of Conflict of Interest

Authors have declared no conflict of interest.

Author's Contributions

The contribution of the authors is equal.

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