The effect of salinity on evapotranspiration, some growth parameters and ion uptake of sweet sorghum

Köksal Aydinşakir[1]*, Cengiz Erdurmuş[1], Cihan Karaca[2]

1 Batı Akdeniz Agricultural Research Institute, Antalya, Türkiye, 07100
2 Akdeniz University, Vocational School of Kumluca, Department of Plant and Animal Production, Antalya, Türkiye, 07070

*Corresponding author: E-mail: koksal.aydinsakir@tarimorman.gov.tr

Keywords: *Mineral composition, NaCl, salinity stress, ion regulation, leaf analysis*

Abstract

This study aimed to determine the effect of different irrigation water salinity levels on growth, evapotranspiration, some growth parameters, and leaves and roots ion uptake in of two different sweet sorghum (*Sorghum bicolor* L.) varieties (Erdurmuş and Uzun) Six different saline irrigation water levels (S_0=0.5 (control), S_1= 1.0, S_2= 2.0, S_4=4.0, S_8= 8.0, and S_{16}=16.0 ds m^{-1}) were obtained by mixing the NaCl and $CaCl_2$ salt sources into the tap water source. Plants were harvested before the phase of florescence. Increasing salinity level first increased and then decreased all growth parameters (Stem length, root length, fresh stem weight, fresh root weight, dry stem weight, and dry root weight). The increased salinity level after S_2 treatment resulted in decreased water use efficiency. The salinity level affected the uptake of all ions in the root (except the K ion) and leaf, and as the salinity level increased, the amount of N, P, Mn, Zn and Na in the leaf increased significantly, while the amount of K, Ca, Mg, Fe and Cu decreased.

Abbreviations

ANOVA: Analysis of variance
BATEM: Batı Akdeniz Agricultural Research Institute
Ca: Calcium
$CaCl_2$: Calcium chloride
Cl: Chloride
cm: Centimeter
Cu: Copper
EC_i: Electrical conductivity
ET: Evapotranspiration
FC: Field capacity
Fe: Iron
g: Gram
$HClO_4$: Perchloric acid
HNO_3: Nitric acid
K: Potassium
L: Liter
LF: Leaching fraction
LSD: Least significant difference
Mg: Magnesium
Mn: Manganese
N: Nitrogen
Na: Sodium
NaCl: Sodium chloride
P: Phosphate
R: Amounts of applied water
SAR: Sodium adsorption ratio
v: Volume
W: Pot weight at the time of weighing
W_{FC}: Pot weight at field capacity
W_n: Pot weight on day n
W_{n+1}: Pot weight on day n+1
Zn: Zinc
ρ_w: Water bulk density

Introduction

To maintain the sustainability of agricultural production, it is important to use salt water in a controlled manner in conditions where clean water resources are limited. Uncontrolled saline irrigation practices increase the soil salinity in the plant root zone, but reduce the yield and quality of the plant due to osmotic stress and unbalanced ion accumulation in the plant leaves (Zhang *et al.*, 2020). Although there are genotypic differences between cultivars, sweet sorghum belongs to the same species as grain sorghum, (*Sorghum bicolor* L. Moench) and is generally considered to be a moderately salt tolerant plant (Yang *et al.*, 1990). Additionally, sweet sorghum is considered one of the best feedstock for

Table 1 - Chemical properties of irrigation waters prepared for different salinity levels

Treatments	EC dS m^{-1}	pH	Anions (me l^{-1})				Cations (me l^{-1})				SAR
			Na	K	Ca	Mg	CO_3^{2-}	HCO_{3-}	Cl	SO_4^{2-}	
S0	0.5	7.7	0.60	0.05	3.25	1.44	-	3.93	1.30	0.11	0.36
S1	1.0	7.9	2.09	0.06	5.28	4.65	-	4.07	6.91	1.10	1.11
S2	2.0	7.7	8.26	0.07	8.78	7.62	-	3.86	14.56	6.31	1.87
S4	4.0	7.7	17.85	0.08	13.65	14.02	-	4.01	25.65	15.94	3.18
S8	8.0	7.6	30.32	0.09	31.34	26.50	-	4.02	52.45	31.78	4.12
S16	16.0	7.6	42.45	0.11	39.68	44.12	-	3.75	87.65	34.96	4.85

ethanol production, due to a favorable combination of agronomic and technological characteristics (Codesido *et al.*, 2013). Previous studies (Tester and Davenport, 2003; Zhang *et al.*, 2020) showed that increasing salinity levels in the plant root zone significantly affected the ion uptake of plants and the distribution of ion contents in plant organs. Additionally, Netondo *et al.*, (2004) reported that increasing NaCl concentration significantly reduces the relative shoot growth rate and shoot dry weight of sorghum. Ionic stress due to high concentrations of toxic ions such as Na^+ and Cl^- reduces uptake of other mineral nutrients such as Ca and K, which causes metabolic disturbances (Hasana and Miyake, 2017). Serrão *et al.* (2012) stated that N is the mineral that limits sorghum production the most, while P and K are also necessary for better productive sorghum. Pollution and decreasing of water resources gradually as a result of global warming and allocation to other sectors (urban and industry) results in the intensive use of marginal quality waters in irrigated agriculture, especially in arid and semi-arid regions. Therefore, researches about the use of saline or marginal quality water in irrigated agriculture are currently being conducted. When the fresh water resources are deficient, saline water is used for irrigation with the precautions taken to prevent any adverse effect on soil and plant. Irrigation water salinity and soil salinity adversely affect crop development and growth, and decrease yield quality considerably. Therefore, salt tolerant plants need to be grown in areas where both soil and water salinity is a problem. The salt threshold values of the crops that will be grown under saline conditions should be known for a successful cultivation and agricultural economy (Aydinsakir *et al.*, 2015). Salinity is an important constraint to crop production in the world. Because of salinity problems, researchers are trying to get the salt resistant vegetables to meet the need of mankind. One of the most effective way to overcome salinity problems is the introduction of salt tolerance to crops. Most of the literature indicates that vegetable crops are particularly susceptible to salinity during the seedling and early vegetative growth stages as compared to germination. In order to perform saline irrigation applications in a more controlled manner it is necessary to determine how plant ion uptake affects different salinity levels for all stage of plant development. For these reason, this study aimed to determine the effect of different irrigation salinities on growth, water consumption, and mineral accumulation in the leaves and roots of the early seedling stage of two different sorghum varieties.

Material and methods

Research area and plant material

This study was carried out in the research area of the Batı Akdeniz Agricultural Research Institute (BATEM) in 2021. In the research, two different sorghum varieties (Uzun and Erdurmuş) adapted for the regional conditions were used as plant material.

Experimental design

The experiment was conducted in a randomized block design with 10 treatments and three blocks, which corresponded to plots in the test area (180 pots in total). To determine the effects of salinity on sorghum plants in the early seedling stage, five different salinity levels with different electrical conductivity (ECi) were used (S_1= 1.0, S_2: 2.0, S_4=4.0, S_8= 8.0 and S_{16}=16.0 ds m^{-1}) in addition to the current tap water (Control treatment, S_0=0.5 ds m^{-1}). During the preparation of saline waters, sodium adsorption ratio (SAR) values of each treatment were maintained less than 5.0 in order to avoid the adverse effect of increasing SAR on soil structure and water gas movement. Each salinity treatment was adjusted by mixing the NaCl and $CaCl_2$ salts. The chemical content of each irrigation water salinity was given in Table 1.

Salinity treatments

The plants were grown in 20 and 18 cm size pots with a volume of 5.0 L in a mixture of peat and perlite (1:1, v:v). All treatments were irrigated with tap water (S_0) for 2 weeks, and after the plants reached the 3-4 leaf stage, the application of different saline water treatments was started. At the beginning of the experiment, all pots were saturated with tap water and planted when the pots reached field capacity. For this purpose, after the water from the pots stopped draining, the available water content was assumed to be the field capacity (FC). The crop water requirement was determined by

Table 2 - The components of evapotranspiration and water use efficiency in Uzun variety

Uzun						
Treatment (dS m^{-1})	Stem length (cm)	Applied water (L)	Drainage water (L)	Pot water depletion (L)	Water use (L)	Water use efficiency (cm L^{-1})
$S_{0.5}$	50.6	32.4	6.5	1.7	27.6	1.8
S_1	50.7	31.1	6.2	1.8	26.7	1.9
S_2	52.6	34.5	6.9	1.8	29.4	1.8
S_4	41.8	33.6	6.7	1.7	28.6	1.5
S_8	44.4	31.1	6.2	1.4	26.3	1.7
S_{16}	20.8	26.9	5.4	1.4	22.9	0.9

weighing the pots every 2-3 days. The amount of applied irrigation water and evapotranspiration were calculated by Equations 1 and 2, respectively (Ünlükara *et al.*, 2010).

$$I = \frac{\frac{W_{FC} - W}{p_w}}{1 - LF} \quad (1)$$

$$ET = \frac{(W_n - W_{n+1})}{p_w} + (1\text{-}R) \quad (2)$$

Where I is the amounts of applied water (l), W_{FC} is the pot weight at field capacity (kg), W is the pot weight at the time of weighing kg), ρ_w is water bulk density (1 kg l^{-1}), LF is the leaching fraction (0.15, Ayers and Westcot, 1985), ET is the evapotranspiration, W_n is the pot weight on day n, W_{n+1} is the pot weight on day $n+1$ and R is the is the amounts of applied water (*l*).

The experiment started with planting seeds into pots on 01.07. 2021 and was completed 45 days after planting (14.08.2021). At the end of the research, all plants were removed from the pots and their roots and stems were separated. Root and stem lengths of plants were measured using the ruler and their weight was measured using digital precision scales. Fresh plant organs were dried in a 72°C oven for 48 hours. Thereafter, length and weight measurements were performed again. Dried leaf samples digested with $HNO_3/HClO_4$ acid mixture (4:1) on a hot plate. Concentrations of P, K, Ca, Mg, Fe, Mn, and Zn were determined by using inductively coupled plasma-optical emission spectrometry (ICP-OES) and N was determined by the modified Kjehldahl method (Kacar and İnal, 2008).

Statistical analysis

Variance analysis (ANOVA) was performed on all data and the differences between the means were compared at the 5% significance level using the LSD test.

Results and discussion

Evapotranspiration and water use efficiency

The components of evapotranspiration (applied water, drainage water, pot water depletion, and water use) and water use efficiency based on the stem length of different salt treatments in Uzun and Erdurmuş varieties are reported in Table 2 and Table 3, respectively.

The amount of irrigation water applied to the Uzun variety ranged from 26.9 to 34.5 liter (Table 2) and from 28.4 to 38.6 liter for the Erdurmuş variety (Table 3). In the two varieties, the largest quantity of irrigation water was applied to the S_2 treatment. Similarly, in both varieties, the highest water usage, namely evapotranspiration, occurred in the S_2 treatment. This indicates that saline water applications up to the S_2 treatment level have a positive effect on plant development. Indeed, the highest stem length of both cultivars occurred in treatment S_2. On the other hand, depending on the plant height, the highest water use efficiency was observed in the S_1 treatment in the Uzun variety, and in S_0 and S_1 treatment in the Erdurmuş variety. The lowest water use efficiency of both cultivars occurred in the S_0 treatment. In other salinity treatments, the water use efficiency ranged from 1.5 to 1.9 cm l^{-1}. Drainage water from the pot was also one of the important components in soil water balance, especially in salinity studies. The difference of drainage amount between treatments depended on the amount of applied water and leaching

Table 3 - The components of evapotranspiration and water use efficiency in Erdurmuş variety

Erdurmuş						
Treatment (dS m^{-1})	Stem length (cm)	Applied water (L)	Drainage water (L)	Pot water depletion (L)	Water use (L)	Water use efficiency (cm L^{-1})
$S_{0.5}$	43.8	28.4	6.7	1.8	23.5	1.9
S_1	50.4	30.8	6.2	1.6	26.2	1.9
S_2	62.4	38.6	6.4	1.6	33.8	1.8
S_4	51.2	33.6	6	1.8	29.4	1.7
S_8	49.8	32.6	6.4	1.3	27.5	1.8
S_{16}	29.4	28.6	5.6	1.2	24.2	1.2

fractions (Aydinşakir *et al.*, 2015). While the pot water depletion was approximately the same from the control treatment (S_0) to the S_4 treatment, after this level, the increasing salt concentration in the irrigation water increased the pot water depletion. This resulted in a decrease evapotranspiration in these treatments (S_8 and S_{16}). In addition, these results show that sorghum is less affected by salt stress up to S_4 level. Reduction of water use and water use efficiency is a common phenomenon of many crop plants grown under saline conditions The current results are similar to results from okra (Ünlükara *et al.* 2008), carrot (Ünlükara *et al.* 2011), fennel (Semiz *et al.* 2012), and peanut (Aydinsakir *et al.*, 2015).

Growth parameters

Table 4 shows the effects of different saline irrigation levels on some growth parameters in the early seedling stage in two different sweet sorghum varieties. The mean stem length and root length of Erdurmuş variety (47.9 and 29.4 cm, respectively) was significantly higher ($p<0.05$ and $p<0.01$, respectively) compared to Uzun variety (43.5 and 22.8 cm, respectively) (Table 4). Salinity level significantly affected the mean stem and root length ($p<0.01$). Stem and root length increased from the control treatment (S_0) to the S_2 treatment depending on the salinity level. However, after the S_2 treatment, the increasing salt amount in the irrigation water caused the stem and root length to decrease gradually. The effect of variety × salinity levels interaction was not significant in stem length but significant in root length (Table 4). However, the numerical values showed that the highest stem and root length belongs to the S_2 treatment. The stem length of Erdurmuş variety varied from 62.4 to 29.4 cm and Uzun variety from 52.6 to 20.8 cm. The highest root length was in S_2 and S_4 treatments of Erdurmuş variety. The results of the present study showed that salinity levels caused a decrease in stem length. However, compared to control treatment, small increase in stem length in the treatments of S_1 and S_2 treatments of Uzun variety was observed. Salinity levels more than S_2 treatment decreased stem length sharply, comparing to the treatment of $S_{0.5}$ and S_1. Stem length in the treatments of S_4, S_8 and S_{16} was lower than that of the treatment of S_2 as much as 20.0 %, 16.0%, and 60.0%. Stem and root length provide an important clue to the response of crops to salt stress (Jamil and Rha, 2004; Aydinşakir *et al.*, 2015). Because the high salinity level in the root zone causes a decrease in the water uptake of the plant due to the osmotic effect. Depending on the severity of this phenomenon, it negatively affects the stem and root development of the plant. In addition, high salt conditions cause toxic effects on plants and reduce plant growth (Werner and Finkelstein, 1995). Statistical differences, between fresh and dry stem weights in the early seedling stage of two different sorghum varieties, have been found (Table 4). While the fresh stem weight of the Erdurmuş variety was higher than the Uzun variety, the dry stem weight of the Uzun variety was higher. This showed that the Uzun variety was superior to the Erdurmuş variety in terms of the dry matter of sorghum in the early seedling stage. Similar results were observed in root weights (fresh and dry). Kır and Dursun Şahan (2019) reported that differences in dry matter accumulation between cultivars were related to ecological conditions of research areas, status of the first and the second crop cultivations, and genetic characteristics of the varieties. In this study, the differences in dry matter accumulation of the varieties depended on the genetic characteristics of the varieties, since the growing conditions were the same. The fresh and dry weights (stem and root) increased significantly due to the increasing salinity level until the S_2 treatment. Fresh and dry stem weights of S_2 and S_4 treatments were higher compared to other treatments. In the S_8 and S_{16} treatments fresh and dry weights (stem and root) decreased significantly due to salinity. This contributes positively to the plant growth of sorghum in the early seedling stage due to the nutritional elements in the salty irrigation applications up to the S_4 treatment (Table 4). Indeed, many studies (Yang *et al.*, 1990; Pescod, 1992; Ali *et al.*, 2021) indicated that sorghum was moderately tolerant of salinity. Netondo *et al.* (2004) determined that the dry weights of the plants varied according to the varieties. The researchers stated that the dry weight of the Serena variety first increased and then decreased depending on the increasing salt, while the Seredo variety was constantly decreasing. The weight changes obtained by drying fresh stems and roots in different varieties and salinity levels gave the water content values in the plant stems. The fresh and dry stem weight changes were between 54.82% - 68.74% in the Erdurmuş variety and 40.15% - 65.08% in the Uzun variety at different salinity levels. These results showed that the water content of the stem was higher in the Erdurmuş variety compared to the Uzun variety in the early seedling growth stage.

Ion uptake

The effects of salinity on ion uptake in roots and leaves in two different sorghum cultivars are given in Tables 5 and 6, respectively. When the mineral contents of the roots of different varieties were examined, there was found a significant difference between the varieties in N, Ca, Mg, Mn and Na minerals, while no difference in P, K, Fe, Zn minerals. While the Uzun variety had more N and Na in the root content, the Erdurmuş variety had more Ca, Mg and Mn. Considering the ion composition in the leaf, all minerals except P showed significant dif-

Table 4 - The effect of different saline irrigation levels on some growth parameters in two different sorghum (*Sorghum bicolor* L.) varieties at early seedling stage

Treatments		Stem length (cm)	Root length (cm)	Fresh stem weight (g plant^{-1})	Fresh root weight (g plant^{-1})	Dry stem weight (g plant^{-1})	Dry root weight (g plant^{-1})
Erdurmus		47.9 a	29.4 a	32.3 a	35.8 a	10.9 b	10.4 b
Uzun		43.5 b	22.8 b	29.1 b	33.3 b	12.2 a	12.4 a
Variety (V)		*	**	**	*	**	**
$S_{0.5}$		47.2 b	25.7 c	28.9 c	42.8 b	11.2 c	11.8 c
S_1		50.6 ab	29.9 b	35.1 b	49.5 a	12.5 b	13.8 b
S_2		57.5 a	33.3 a	40.8 a	52.6 a	14.2 a	16.3 a
S_4		46.5 b	30.4 b	39.6 a	35.6 c	13.6 a	12.3 c
S_8		47.1 b	24.0 c	24.7 d	17.4 d	10.1 d	7.8 d
S_{16}		25.1 c	13.4 d	15.2 e	9.7 e	7.8 e	6.5 e
Irrigation water salinity level (S)		**	**	**	**	**	**
Erdurmus	$S_{0.5}$	43.8	26.2 ce	28.5	45.0 cd	10.0 e	12.0 de
	S_1	50.5	31.0 b	35.0	50.4 ac	11.0 de	12.3 d
	S_2	62.4	38.2 a	41.8	51.0 ab	13.1 bc	13.9 c
	S_4	51.2	36.7 a	43.5	34.4 f	13.6 bc	10.9 e
	S_8	49.8	27.7 cd	28.6	23.7 g	10.1 e	7.7 f
	S_{16}	29.4	16.7 g	16.6	10.5 h	7.5 f	5.7 g
Uzun	$S_{0.5}$	50.6	25.2 de	29.3	40.5 de	12.3 cd	11.7 de
	S_1	50.7	28.8 bc	35.2	48.7 bc	13.9 b	15.3 b
	S_2	52.6	28.3 bc	39.8	54.2 a	15.3 a	18.6 a
	S_4	41.8	24.2 e	35.7	36.8 ef	13.5 bc	13.7 c
	S_8	44.4	20.3 f	20.9	11.0 h	10.2 e	7.8 f
	S_{16}	20.8	10.2 h	13.7	8.8 h	8.2 f	7.2 f
V × S		**ns**	**	**ns**	**	*	**

*, **, and ns, Significant at the $p< 0.05$, $p< 0.01$ level, and not significant, respectively. The means indicated with the same small letter in the same column are not significantly different ($p<0.05$)

ferences depending on the varieties. While N, K, Ca, Fe, Mn and Na contents were higher in Uzun variety, Mg, Zn and Cu contents were higher in Erdurmuş variety (Table 5). Increasing salinity levels caused significant differences in all leaf minerals ($p<0.01$) (Table 6). Although increasing salinity level had the same effect on root mineral contents, only K was not affected. The effect of salinity level on root minerals can be categorized into 4 groups. Depending on the increasing salinity level; 1: first increasing and then decreasing (N, Ca, and Mg), 2: increasing (P, Zn, and Na), 3: decreasing (Fe, Mn, and Cu), and 4: unchanged (Table 5). Whereas the content of N and Mg in roots increased up to S_2, the content of Ca increased up to S_4 and the increasing salinity level from these levels caused a significant decrease in these ion contents. These results were in harmony with the values of plant growth parameters. It can be said that the decrease in root and stem length in the early seedling stage at high salt concentrations is the inhibition of cell division and elongation due to the toxic effect of salts. However, the decrease in root and stem elongation can be caused by the reduction in the internal amount of growth-promoting hormones due to salt stress and the increase in the level of growth-inhibiting hormones (Aydinşakir *et al.*, 2012). Leaf mineral contents of sorghum increased significantly (N, P, Mn, Zn, and Na) or decreased (K, Ca, Mg, Fe, and Cu) depending on the increasing salinity level in the early seedling stage ($p<0.01$). Netondo *et al.* (2004) stated that due to the negative effect of NaCl on the allocation of K, Ca and Mg to the leaf tissues, these minerals decreased in the leaves and this would cause metabolic deterioration (Table 6). Although there was no significant difference in the K content in the root, significantly decreased in the leaf due to the increasing salinity level ($p<0.01$). Munns and Termaat (1986) stated that the K content in the leaves would decrease because salinity could cause a rapid decrease in the transport of essential nutrients to the stem. Maas *et al.* (1986) reported that salinity stress affects the leaf mineral composition of sorghum differently in vegetative, reproductive, and maturity stages. Tester and Davenport (2003) noted that salt-tolerant plants tend to take up Na more easily. Increasing levels of salinity led to a significant rise in Na

Table 5 - The effect of different saline irrigation levels on root ion composition in two different sorghum (*Sorghum bicolor* L.) varieties at early seedling stage

Treatments		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Na (ppm)
Erdurmus		0.99 b	0.05	0.22	2.02 a	0.40 a	3267.6	114.8 a	40.9	219.1	8888 b
Uzun		1.17 a	0.05	0.20	1.72 b	0.32 b	3410.1	89.7 b	41.4	207.8	9409 a
Variety (V)		**	ns	ns	**	**	ns	**	ns	ns	*
$S_{0.5}$		1.08 bc	0.04 d	0.20	1.65 bc	0.38 b	4560.0 a	121.5 a	28.9 c	252.3 a	1522 e
S_1		1.11 b	0.05 c	0.21	1.92 ab	0.40 ab	4242.8 ab	116.3 ab	31.5 c	254.9 a	3015 d
S_2		1.04 a	0.05 c	0.21	2.13 a	0.43 a	4144.2 ab	108.1 bc	34.4 c	237.5 a	3838 d
S_4		1.08 c	0.05 bc	0.20	2.05 a	0.38 b	3760.8 b	100.2 cd	36.4 c	244.5 a	8020 c
S_8		0.99 d	0.06 b	0.23	1.64 c	0.33 c	1959.5 c	90.9 d	50.9 b	158.7 b	12737 b
S_{16}		1.19 e	0.07 a	0.23	1.87 bc	0.25 d	1365.7 d	76.5 e	64.7 a	132.7 c	25758 a
Irrigation water salinity level (S)		**	**	ns	**	**	**	**	**	**	**
Erdurmus	$S_{0.5}$	1.03 e	0.03	0.20	1.75 ce	0.38 cd	4625.3	128.9 a	29.0	260.9 a	2017 gh
	S_1	0.99 ef	0.04	0.20	2.26 ab	0.44 ab	4015.0	121.9 ab	34.4	254.5 ab	3483 ef
	S_2	0.94 f	0.05	0.20	2.49 a	0.49 a	3993.7	113.7 bc	35.8	229.5 b	4360 e
	S_4	0.91 fg	0.05	0.23	1.98 bc	0.42 bc	3333.7	110.1 bc	36.2	227.2 b	8367 d
	S_8	0.84 g	0.06	0.26	1.77 ce	0.38 cd	1939.0	108.3 bc	54.2	175.0 c	12500 c
	S_{16}	1.22 ac	0.07	0.26	1.90 bd	0.30 ef	1699.0	105.8 c	55.8	167.3 cd	22600 b
Uzun	$S_{0.5}$	1.13 d	0.04	0.20	1.55 de	0.38 cd	4494.7	114.0 bc	28.7	243.8 ab	1027 h
	S_1	1.23 ab	0.05	0.22	1.57 de	0.36 d	4470.7	110.6 bc	28.6	255.3 ab	2547 fg
	S_2	1.14 cd	0.04	0.21	1.76 ce	0.36 d	4294.7	102.4 cd	33.1	245.4 ab	3317 ef
	S_4	1.24 a	0.05	0.17	2.12 ac	0.34 de	4188.0	90.3 d	36.5	261.9 a	7673 d
	S_8	1.13 d	0.05	0.19	1.50 e	0.27 f	1980.0	73.5 e	47.6	142.4 d	12973 c
	S_{16}	1.15 bd	0.07	0.19	1.83 ce	0.19 g	1032.3	47.3 f	73.6	98.1 e	28917 a
V x S		**	ns	ns	*	*	ns	**	ns	**	**

*, **, and ns, Significant at the $p < 0.05$, $p < 0.01$ level, and not significant, respectively. The means indicated with the same small letter in the same column are not significantly different ($p<0.05$)

concentration both in stem and root ($P<0.01$). Netondo *et al.* (2004), who obtained similar results, reported that Na accumulation in leaves was directly proportional to leaf age. The researchers reported that increased Na leads to a lower Ca concentration in the xylem fluid and in turn, to a lower Ca supply to the leaf tissues. The growth under salinity stress conditions could be inhibited by a reduction in K concentration that reduces osmotic adjustment capacity and retention of turgor or adversely affecting metabolic functions. Although Na is not an essential element for the plant, it accumulates Na in plant organs to reduce Ca and K due to salt stress (Amirjani, 2010). Similarly Zhang *et al.* (2020) suggested that K/Na and Ca/Na ratios were associated with tolerance under salt-stressed environments and higher Na and lower K and Ca concentrations were deleterious to sorghum growth. Although the increase in salinity did not significantly affect the amount of K in the roots, it resulted in a decrease in the stems. Netondo *et al.* (2004) reported that the increasing salinity level had a different effect on the K content in the leaf blades and sheaths. The researchers stated that NaCl application had no effect on the K concentration in the leaf blades, but it would cause a significant reduction in the leaf sheaths. The effect of variety × salinity level interactions differed depending on the minerals in the leaves and roots. While N, Ca, Mg, and Na contents in both leaves and roots were significantly affected by the interactions of variety × salinity level, P and Zn were not

Conclusions

This study aimed to investigate the effect of increasing salt concentration on some plant growth parameters and ion uptake in leaves and roots in two different sorghum cultivars in the early seedling stage. In both cultivars, the highest ET occurred under S_2 treatment. Related to this result, S_2 treatment plants had the highest stem and root length and fresh and dry root weight. The highest fresh and dry weights occurred in S_2 and S_4 treatments. This result showed that salinity had a positive effect on plant growth up to S_2 and S_4 levels. There were differences in the ion uptake of sorghum roots and leaves depending on the salinity level. Increasing salinity levels caused significant differences in the upta-

Table 6 - The effect of different saline irrigation levels on leaf ion composition in two different sorghum (*Sorghum bicolor* L.) varieties at early seedling stage

Treatments		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Na (ppm)
Erdurmus		1.44 b	0.086	1.16 b	0.79 b	0.45 a	48.94 b	32.8 b	77.6 a	7.54 a	3093 b
Uzun		1.58 a	0.100	1.36 a	0.90 a	0.37 b	64.13 a	42.9 a	66.9 b	6.83 b	7149 a
Variety (V)		**	ns	**	**	**	**	**	**	**	**
$S_{0.5}$		1.38 bd	0.06 c	1.34 a	1.46 a	0.51 a	89.42 a	25.2 e	47.8 e	10.7 a	180 c
S_1		1.41 bc	0.07 c	1.33 a	0.92 b	0.48 a	63.40 b	28.1 d	53.2 de	8.6 b	698 c
S_2		1.35 cd	0.07 c	1.32 a	0.80 c	0.43 b	57.12 bc	31.8 c	59.1 cd	7.0 c	1438 c
S_4		1.47 b	0.09 bc	1.27 a	0.72 cd	0.42 b	51.10 c	44.0 b	64.2 c	6.1 d	3458 b
S_8		1.28 d	0.11 b	1.26 a	0.63 de	0.35 c	39.47 d	44.9 b	78.2 b	5.8 de	4667 b
S_{16}		2.16 a	0.17 a	1.04 b	0.56 e	0.27 d	38.72 d	53.1 a	131.2 a	5.0 e	20288 a
Irrigation water salinity level (S)		**	**	**	**	**	**	**	**	**	**
Erdurmus	$S_{0.5}$	1.36 ce	0.04	0.61 e	0.59 e	0.60 a	96.37 a	21.4	57.5	10.5	247 g
	S_1	1.38 cd	0.06	1.08 d	0.63 de	0.56 a	46.67 e	24.8	59.1	8.9 b	880 fg
	S_2	1.20 e	0.06	1.12 d	0.77 cd	0.46 b	44.53 ef	27.1	62.1	7.6	1393 eg
	S_4	1.30 de	0.08	1.31 ac	0.80 c	0.46 b	42.43 eg	38.4	65.3	6.7	2783 df
	S_8	1.28 de	0.12	1.40 ab	0.81 c	0.35 d	32.37 fg	38.5	82.6	6.3	3350 de
	S_{16}	2.11 a	0.16	1.45 a	1.17 b	0.26 e	31.30 g	46.7	139.0	5.2	9910 b
Uzun	$S_{0.5}$	1.40 cd	0.07	1.46 a	0.52 e	0.43 bc	82.47 b	28.9	38.0	10.8	113 g
	S_1	1.44 cd	0.08	1.47 a	0.62 de	0.41 bd	80.13 bc	31.5	47.3	8.2	517 fg
	S_2	1.49 bc	0.09	1.39 ac	0.67 ce	0.39 cd	69.70 cd	36.5	56.0	6.5	1483 eg
	S_4	1.64 b	0.09	1.36 ac	0.81 c	0.38 cd	59.77 d	49.7	63.2	5.6	4133 cd
	S_8	1.28 de	0.10	1.23 bd	1.04 b	0.35d	46.57 e	51.2	73.7	5.2	5983 c
	S_{16}	2.20 a	0.18	1.21 cd	1.75 a	0.28 e	46.13 e	59.4	123.4	4.7	30667 a
V x S		*	ns	**	**	**	**	ns	ns	ns	**

*, **, and ns, Significant at the $p< 0.05$, $p< 0.01$ level, and not significant, respectively. The means indicated with the same small letter in the same column are not significantly different ($p<0.05$)

ke of all ions in leaves and roots (except the K ion in the root). As the salinity level increased, the uptake of N, P, Mn, Zn and Na ions increased, while the uptake of K, Ca, Mg, Fe and Cu ions decreased. It is concluded that both varieties tolerate salinity up to 2 dSm^{-1} based on leaf and root ion uptake values.

References

Ali AYA, Ibrahim MEH, Zhou G, Nimir NEA, Elsiddig AMI, Jiao X, Zhu G, Salih EGI, Suliman MSES, Elradi SBM, 2021. Gibberellic acid and nitrogen efficiently protect early seedlings growth stage from salt stress damage in Sorghum. Scientific Reports 11(6672):1–11.

Amirjani MR, 2010. Effect of salinity stress on growth, mineral composition, proline content, antioxidant enzymes of soybean. American Journal of Plant Physiology 5(6): 350–360.

Aydinşakir K, Erdurmus C, Buyuktas D, Çakmakcı S, 2012. The effect of salt (NaCl) stress on germination and early seedling growth of some silage sorghum (*Sorghum bicolor*) varieties. Mediterranean Agricultural Sciences 25(1): 47–52.

Aydinşakir K, Büyüktaş D, Dinç N, Karaca C, 2015. Impact of salinity stress on growing, seedling development and water consumption of peanut (*Arachis hypogea* cv. NC-7). Mediterranean Agricultural Sciences 28(2): 77–84.

Ayers AS, Westcot DW, 1985. Water quality for agriculture. Rome: FAO Irrigation and Drainage Paper 20.

Codesido V, Vacas R, Macarulla B, Gracia MP, Igartua E, 203. Agronomic and digital phenotyping evaluation of sweet sorghum public varieties and F1 hybrids with potential for ethanol production in Spain. Maydica 58(1):42-53.

Hasana R, Miyake H, 2017. Salinity stress alters nutrient uptake and causes the damage of root and leaf anatomy in maize. KnE Life Sciences 3(4): 219–225.

Jamil M, Rha E-S, 2004. The effect of salinity

(NaCl) on the germination and seedling of sugar beet (*Beta vulgaris* L.) and cabbage (*Brassica oleracea* L.). Korean Journal of Plant Research 7: 226–232.

Kacar B, İnal A, 2008. Plant analysis. Nobel Publication, Ankara, Turkey.

Kır H, Dursun Şahan B, 2019. Yield and quality feature of some silage sorghum and Sorghum-Sudangrass hybrid cultivars in ecological conditions of Kirşehir province. Turkish Journal of Agricultural and Natural Sciences 6(3): 388–395.

Maas E V., Poss JA, Hoffman GJ, 1986. Salinity sensitivity of sorghum at three growth stages. Irrigation Science 7: 1–11.

Munns R, Termaat A, 1986. Whole-plant responses to salinity. Australian Journal of Plant Physiology 13(1): 143–160.

Netondo GW, Onyango JC, Beck E, 2004. Sorghum and salinity: I. Response of growth, water relations, and ion accumulation to NaCl salinity. Crop Science 44(3): 797–805.

Pescod M, 1992. Waste water treatment and use in agriculture. Rome: FAO Irrigation and Drainage Paper No: 47.

Serrão MG, Menino MR, Martins JC, Castanheira N, Lourenço ME, Januário I, Fernandes ML, Gonçalves MC, 2012. Mineral leaf composition of sweet sorghum in relation to biomass and sugar yields under different nitrogen and salinity conditions. Communications in Soil Science and Plant Analysis 43(18): 2376–2388.

Tester M, Davenport R, 2003. Na+ tolerance and Na+ transport in higher plants. Annals of Botany 91(5): 503–527.

Ünlükara A, Kurunç A, Kesmez GD, Yurtseven E, Suarez DL, 2010. Effects of salinity on eggplant (*Solanum melongena* L.) growth and evapotranspiration. Irrigation and Drainage 59: 203–214.

Werner JE, Finkelstein RR, 1995. Arabidopsis mutants with reduced response to NaCl and osmotic stress. Physiologia Plantarum 93(4): 659–666.

Yang YW, Newton RJ, Miller FR, 1990. Salinity tolerance in Sorghum. I. whole plant response to sodium chloride in *S. bicolor* and *S. halepense*. Crop Science 30(4): 775–781.

Zhang F, Sapkota S, Neupane A, Yu J, Wang Y, Zhu K, Lu F, 2020. Effect of salt stress on growth and physiological parameters of sorghum genotypes at an early growth stage. Indian Journal of Experimental Biology 58: 404–411.