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## Ameliorative Effects of Zinc on Pistachio (*Pistacia vera* L.) Growth under Salt-Affected Soil Conditions

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**Abstract:** A greenhouse study was conducted to evaluate the ameliorative effects of Zn (0, 5, 10 and 20 mg Zn kg<sup>-1</sup> soil) under saline (800, 1600, 2400 and 3200 mg NaCl kg<sup>-1</sup> soil) and normal conditions on pistachio seedlings (*Pistacia vera* L. cv. Badami) growth and performance. Zinc improved plant growth under salt-affected soil conditions. Plants biomass was strongly decreased by salinity level of 3200 mg kg<sup>-1</sup> and the soil adverse effects were accentuated with increasing level of salinity. Increasing salinity in soil under Zn deficient conditions, generally decreased leaf, shoot and root fresh and dry weight and other growth parameters. However, these adverse effects of salinity diminished with the increase in Zn levels up to 10 mg kg<sup>-1</sup>. Increasing Zn supply from 5 to 10 mg kg<sup>-1</sup> soil improved net assimilation rate, relative growth rate, leaf area ratio and specific leaf area under salinity conditions. Zn also had significant effect on increasing total leaf area, shoot height, stem diameter and number of leaves under salinity stress. The result of the present study emphasized the importance of Zn nutritional status of plants in improving salt stress tolerance. Adequate Zn nutrition is, therefore, important for the maintenance of good pistachio tree growth and yield under saline conditions. Zn fertilization markedly increases pistachio biomass, shoot height, leaf number, stem diameter, net assimilation rate, relative growth rate, leaf area ratio and specific leaf area at all salinity levels. These growth indices are markedly reduced when the amount of Zn in media is below optimum levels under salinity conditions.

**Key words:** Growth parameters, net assimilation rate, pistachio (*Pistacia vera* L.), relative growth rate, salinity stress, zinc

## INTRODUCTION

Soil salinization is one of the major factors contributing to soil degradation. Salt affected soil cover 19.5% of the irrigated land and 2.1% of the dry farming land world wide (FAO, 2000). Continuous cropping together with an excessive use of chemical fertilizers and ill-managed irrigation have turned hundreds of cultivated fertile lands into saline soil. Saline soil contain sufficient soluble salts to suppress plant growth through a series of interacting factors such as osmotic effect, specific ion toxicities and antagonisms which induce nutrient imbalance (Grattan and Grieve, 1998).

Pistachio nut trees (*Pistacia vera* L.) have been grown commercially in Iran for many years and currently, pistachio plantations covers about 390, 000 ha with an annual production of around 150000 ton of pistachio nuts. Most pistachio plantations are on sodic soil and are irrigated with low quality, saline water. Poor quality of irrigation water in association with sodic soil has reduced yields of pistachio over recent years, especially in Kerman in the South-East of Iran and also in Central Iran,

particularly in Yazd and Qhom regions. Despite reduced yields with increasing salinity, pistachio has been described as salt tolerant plant (Sepaskhah and Maftoun 1981; Behboudian *et al.*, 1986; Picchioni and Miyamota 1990; Ferguson *et al.*, 2002) and is potentially used as an alternative to salt-sensitive pecan (*Carya illinoensis*) or almond (*Prunus amygdalus*). Symptoms of salt toxicity in pistachio and cultivar differences in susceptibility to salinity have been previously described by Sepaskhah and Maftoun (1981), Behboudian *et al.* (1986), Picchioni and Miyamota (1990) and Ferguson *et al.* (2002). For example, salinity stress can cause decreased growth, alter photosynthetic rates and cause morphological changes in the leaves (Behboudian *et al.*, 1986; Picchioni and Miyamota, 1990; Ranjbar *et al.*, 2002; Munns *et al.*, 2002). Salinity reduces shoot growth by suppressing leaf initiation and expansion as well as internode growth and by accelerating leaf abscission (Zekri and Parsons, 1990; Zekri, 1991). The loss of leaves decreases the availability of photosynthetate to meristematic regions, thereby suppressing growth.

Zinc (Zn) deficiency is the most widespread micronutrient deficiency worldwide (Graham *et al.*, 1992; Welch *et al.*, 1991). It is estimated that about 50% of soil used for plantations in the world have low levels of plant-available Zn (Graham and Welch, 1996). Phytoavailability of Zn in calcareous and salt-affected soil of central Iran is low (Khoshgoftarmanesh *et al.*, 2005). Both the high pH and  $\text{CaCO}_3$  content of these soil are usually considered the reasons for the low availability of Zn (Karimian and Moafpouryan, 1999). Several physiological processes are impaired in plants suffering from Zn deficiency. Zinc deficiency causes rapid inhibition of plant growth and development and thus reducing the final yield. Zinc plays a fundamental role in several critical cellular functions such as protein metabolism, gene expression, structural and functional integrity of biomembranes, photosynthetic C metabolism and IAA metabolism (Marschner, 1995). Zinc supply could mitigate the adverse effects of NaCl (Marschner and Cakmak, 1986; Parker *et al.*, 1992). Alpaslan *et al.* (1999) concluded that in the salt affected areas, zinc application could alleviate Na and Cl injury in plants.

Information about the effects of zinc on salt tolerance of pistachio plants are scarce and the aim of the present study is how to decrease the harmful effects of soil salinity on *Pistacia vera* L. plants by zinc application.

## MATERIALS AND METHODS

The experiments were conducted from February 2008 to December 2008 at the Agricultural Research Greenhouse of Shiraz University. Soil used in these studies was a loamy taken from 0-30 cm depth of Chitgar series soil (Fine-loamy, carbonatic, thermic Typic Calcixerepts) located at sarvestan township, 85 km Southeast of Shiraz. Some physical and chemical properties of this soil are given in Table 1. The soil samples were air-dried, crushed to pass through a 2 mm sieve and zinc treatments were combined thoroughly with soil and supplied at the rate of 0, 5, 10 and 20 mg  $\text{kg}^{-1}$  soil as  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ . Zinc treated soil were put in plastic pots at the rate of 7.5 kg  $\text{pot}^{-1}$ . Pistachio (*Pistacia vera* L.cv. Badami) seeds were placed in muslin sacks and were soaked for 24 h in 0.4% captan solution. Seeds were then planted in sand and kept at 30°C for one week. Eight germinated seeds were planted in each pot and pots were irrigated with deionized water twice a week to keep the soil water content higher than the field capacity (on 20%, soil dry weight basis). Nitrogen and P at the rate of 50 and Cu and Mn at the rate of 5 mg  $\text{kg}^{-1}$  soil were applied uniformly to all pots each as  $\text{NH}_4\text{NO}_3$ ,

Table 1: Some physical and chemical properties of the soil used in experiments

Texture	Water content (% dry wt. basis)				NaHCO <sub>3</sub> - extractable P (mg $\text{kg}^{-1}$ soil)	NH <sub>4</sub> OAC- extractable K (mg $\text{kg}^{-1}$ soil)	CEC (Cm, $\text{kg}^{-1}$ )	DTPA- extractable Zn (mg $\text{kg}^{-1}$ soil)
	Field capacity	Permanent wilting point	pH	EC <sub>e</sub> (dS $\text{m}^{-1}$ )				
Loam	20	10	7.8	1.2	13.5	63	12	1.7

$\text{KH}_2\text{PO}_4$ ,  $\text{CuSO}_4$ ,  $5\text{H}_2\text{O}$  and  $\text{MnSO}_4 \cdot \text{H}_2\text{O}$ , respectively. After 25 days the 4-leaved seedlings were thinned to four per pot. Seven days later, salt treatments of 0 (control), 800, 1600, 2400 and 3200 mg  $\text{NaCl kg}^{-1}$  soil were added to the pots at 3-day intervals using 0.5 L irrigation water. Treatments were arranged in a factorial experiment based on Completely Randomized Design (CRD) with 4 replications.

### Growth Parameters

50 and 100 days after salt treatment, pistachio seedlings were harvested and divided into stem, leaf and root components. Roots were separated from the soil by washing them onto sieves and then manually separating roots from any remaining soil and organic debris. Fresh weights of all components were recorded. Total leaf areas of each seedling were recorded with portable leaf area meter Model AM 200 (ADC Bioscientific). Number of leaves, stem height and basal diameter were also recorded both before and after salt treatment. The number of fully expanded mature leaves per plant was recorded. Stem height was measured using a ruler. The change in stem diameter was determined for each plant by measuring the diameter at a height of 2 cm from the stem base using vernier caliper. After each harvest, plant materials were washed first with tap water and then twice with deionized water, before being oven-dried at  $70^\circ\text{C}$  to attain a constant weight for biomass estimation (dry weight). Growth analysis was evaluated according to Hunt *et al.* (2002) and the Relative Growth Rate (RGR), Leaf Area Ratio (LAR), Net Assimilation Rate (NAR) and Specific Leaf Area (SLA) were determined as follows:

- Relative Growth Rate (RGR) defined as the increase in plant weight per unit plant weight per unit time:

$$\text{RGR} = (\ln \text{DM}_2 - \ln \text{DM}_1) (t_2 - t_1)^{-1} (\text{mg} / \text{mg} / \text{day})$$

- Leaf Area Ratio (LAR) was calculated as the ratio between the total leaf area and the total plant dry weight:

$$\text{LAR} = \left( \frac{\text{LA}_1 / \text{DM}_1 + \text{LA}_2 / \text{DM}_2}{2} \right) (\text{mm}^2 / \text{mg})$$

- Net Assimilation Ratio (NAR) on a leaf area basis was defined as the rate of growth (total weight per unit leaf area) over the time intervals ( $t_1$  to  $t_2$ ). Thus:

$$\text{NAR} = \left[ (\text{DM}_2 - \text{DM}_1) (\text{LA}_2 - \text{LA}_1)^{-1} \right] \left[ (\ln \text{LA}_2 - \ln \text{LA}_1) (t_2 - t_1)^{-1} \right] (\text{mg} / \text{mm}^2 / \text{day})$$

- Specific Leaf Area (SLA) was calculated by mean area of leaf per unit of leaf weight:

$$\text{SLA} = \left( \frac{\text{LA}_1 / \text{LDM}_1 + \text{LA}_2 / \text{LDM}_2}{2} \right) (\text{mm}^2 / \text{mg})$$

where,  $\text{DM}_1$  is the initial total (stem+leaf+root) dry mass,  $\text{DM}_2$  is the final total dry mass,  $\text{LA}_1$  is the initial leaf area,  $\text{LA}_2$  is the final leaf area,  $\text{LDM}_1$  is the initial leaf dry mass,  $\text{LDM}_2$  is the final leaf dry mass and  $(t_2 - t_1)$  the differences in time interval between the two sampling times (50 day).

Treatments were arranged in a completely randomized design with 20 treatments. The measurements were made on 4 pots and 4 plants in each pot. The layout was a  $5 \times 4$  factorial arrangement with four replications. Analysis of variance was performed using the SPSS software package and significant difference among the mean values was compared by Tukey test ( $p < 0.05$ ).

## RESULTS AND DISCUSSION

Leaf, shoot and root fresh and dry weights were significantly reduced as the salinity increased, whereas, the main effects of salinity at 800 mg NaCl kg<sup>-1</sup> soil on shoot dry weight and root fresh and dry weights were not statistically significant as compared with control. Regardless of salt concentration, growing plants in Zn-deficient soil and without Zn supply significantly reduced plants leaves, shoot and root fresh and dry matter (Table 2, 3). Zinc application at 5, 10 and 20 mg kg<sup>-1</sup> soil significantly enhanced leaves, shoots and roots fresh and dry weights. Interaction of 10 mg Zn kg<sup>-1</sup> soil with all NaCl levels showed significant increase in leaves, shoots and roots fresh and dry matter as compared with other zinc levels at each NaCl treatment. Similarly it has been shown that zinc (applied at 15 mg kg<sup>-1</sup> soil) has increased shoots and roots dry weight at 60, 120 and 180 mM NaCl as compared with treatments without zinc in 6 wheat genotypes (Khoshgofarmanesh *et al.*, 2006). Aktas *et al.* (2006) have also reported that adequate supply of Zn (e.g., 2 or 10 mg Zn kg<sup>-1</sup> soil) has enhanced shoot dry matter production by nearly 3-fold at three different levels of NaCl in pepper plants. It has also been reported that the fresh and dry weights of tomato plants have increased with the increase in Zn concentration in saline soil (30 mM NaCl) (Alpaslan *et al.*, 1999).

Table 2: Effects of NaCl and Zn on leaf fresh weight (g), shoot fresh weight (g), root fresh weight (g) and total leaf area (mm<sup>2</sup>) of pistachio seedlings

Treatments (mg kg <sup>-1</sup> )		Fresh weight (g)			Total leaf area (mm <sup>2</sup> )
Zinc	NaCl	Leaf	Shoot	Root	
0	0	1.453fg*	1.571gh	1.791ef	4321.25g
5		2.493c	2.094d	2.454cd	5406.75c
10		3.218a	3.373a	3.424a	6818.50a
20		1.830e	2.107d	2.157cde	5208.25cde
0	800	1.438fg	1.410hi	1.774ef	4232.50gh
5		2.138d	2.036de	2.544bc	5330.50cd
10		3.107a	3.235ab	3.372a	6731.25a
20		1.806e	2.051e	2.037def	5166.00cdef
0	1600	1.396g	1.353ij	1.616fg	3918.75hi
5		1.817e	1.872ef	2.116cde	5012.25def
10		2.835b	3.113b	2.393cd	6487.00a
20		1.569f	1.814f	1.829ef	4945.00ef
0	2400	1.042h	0.984k	1.104h	3443.75j
5		1.493fg	1.593gh	1.790ef	4830.00f
10		2.399c	2.531c	2.921b	6054.25b
20		1.005h	1.265ij	1.730ef	4484.00g
0	3200	0.597i	0.668l	0.536i	2597.75k
5		1.005h	1.190j	1.239gh	4307.25g
10		1.579f	1.767fg	2.483bcd	5468.75c
20		0.729i	0.819kl	1.037h	3854.75i
<b>Means</b>					
NaCl (0 mg kg <sup>-1</sup> )		2.248A	2.286A	2.449A	5438.68A
NaCl (800 mg kg <sup>-1</sup> )		2.121B	2.183B	2.432A	5365.06A
NaCl (1600 mg kg <sup>-1</sup> )		1.904C	2.038C	1.989B	5090.75B
NaCl (2400 mg kg <sup>-1</sup> )		1.485D	1.594D	1.886B	4703.00C
NaCl (3200 mg kg <sup>-1</sup> )		0.977E	1.111E	1.323C	4057.12D
Zn (0 mg kg <sup>-1</sup> )		1.185D	1.197D	1.364D	3702.80D
Zn (5 mg kg <sup>-1</sup> )		1.789B	1.757B	2.028B	4977.35B
Zn (10 mg kg <sup>-1</sup> )		2.627A	2.804A	2.919A	6311.95A
Zn (20 mg kg <sup>-1</sup> )		1.388C	1.611C	1.751C	4731.60C
<b>Significance</b>					
NaCl		**	**	**	**
Zn		**	**	**	**
NaCl×Zn		**	**	**	**

\*Means followed by the same letter (small letters for means and capital letters for means of rows and columns) are not significantly different at 5% level of probability using Tukey test. \*, \*\*Significant at p = 0.05 or 0.01, respectively

Table 3: Effects of NaCl and Zn treatments on leaf dry weight (g), shoot dry weight (g) and root dry weight (g) of pistachio seedlings

Treatments (mg kg <sup>-1</sup> )		Dry weight (g)		
Zinc	NaCl	Leaf	Shoot	Root
0	0	0.771f*	0.775ef	0.922efgh
5		1.196c	1.012c	1.213d
10		1.763a	1.744a	1.844a
20		0.939d	0.996c	1.116def
0	800	0.753f	0.742fg	0.885fghi
5		1.099c	0.980c	1.204de
10		1.682ab	1.728a	1.808a
20		0.898de	0.967c	1.057defg
0	1600	0.705f	0.706fgh	0.777ghij
5		0.927d	0.920cd	1.078def
10		1.598b	1.699a	1.706ab
20		0.794ef	0.903cd	0.899fghi
0	2400	0.281i	0.565ig	0.552jkl
5		0.784ef	0.813def	0.872fghi
10		1.211c	1.298b	1.507bc
20		0.547g	0.646ghi	0.762hijk
0	3200	0.525gh	0.306k	0.296l
5		0.541g	0.584hi	0.600ijk
10		0.824def	0.901cde	1.257cd
20		0.408h	0.446g	0.482kl
<b>Means</b>				
NaCl (0 mg kg <sup>-1</sup> )		1.167A	1.131A	1.274A
NaCl (800 mg kg <sup>-1</sup> )		1.108B	1.104AB	1.238AB
NaCl (1600 mg kg <sup>-1</sup> )		1.006C	1.057B	1.112B
NaCl (2400 mg kg <sup>-1</sup> )		0.767D	0.831C	0.923C
NaCl (3200 mg kg <sup>-1</sup> )		0.513E	0.559D	0.659D
Zn (0 mg kg <sup>-1</sup> )		0.607D	0.619D	0.686D
Zn (5 mg kg <sup>-1</sup> )		0.909B	0.862B	0.993B
Zn (10 mg kg <sup>-1</sup> )		1.415A	1.474A	1.624A
Zn (20 mg kg <sup>-1</sup> )		0.717C	0.791C	0.861C
<b>Significance</b>				
NaCl		**	**	**
Zn		**	**	**
NaCl×zn		**	**	**

\*Means followed by the same letter (small letters for means and capital letters for means of rows and columns) are not significantly different at 5% level of probability using Tukey test. \*, \*\*Significant at p = 0.05 or 0.01, respectively

By increasing salinity, total leaf area significantly reduced, except at first salinity level (800 mg NaCl kg<sup>-1</sup> soil) as compared with control (Table 2). Similar results have been reported by Sepaskhah and Maftoun (1981) for *Pistacia vera* L. They showed that the salt concentrations with electrical conductivities of 3.5 and 4.5 mmhos cm<sup>-1</sup> resulted in a significant reduction in the leaf area. The treatments of interaction between soil salinity and zinc application (especially at 10 mg kg<sup>-1</sup>) resulted in a significant increase of total leaf area in comparison with those treatments without zinc (Table 2). Salinity reduces shoot growth by suppressing both leaf initiation and expansion as well as internodes elongation and also by accelerating leaf abscission (Zekri, 1991). Salinity induces early leaf shedding in both angiosperms and gymnosperms (Dragstad, 1973).

Salt treatments also reduced relative plant height, relative number of leaves and relative stem diameter in pistachio seedlings, compared with control (Table 4). Musyimi *et al.* (2007) have reported similar results for avocado seedlings. Zinc significantly improved these parameters when added to each salinity treatment at two zinc levels (5 and 10 mg kg<sup>-1</sup> soil). However, their magnitudes were lower than those of control (0 mg NaCl kg<sup>-1</sup> soil). Welch *et al.* (1982) concluded that Zn must be continuously present in the external media during plant growth. With respect to relative plant height, there was a sharp decrease in these parameters at the three different NaCl levels (1600, 2400 and

Table 4: Effects of NaCl and Zn treatments on relative plant height (%), relative number of leaf (%) and relative stem diameter (%) of pistachio seedlings

Treatments (mg kg <sup>-1</sup> )		Relative plant height	Relative No. of leaf	Relative stem diameter
Zinc	NaCl	----- (%) -----		
0		11.27b*	2.200e	30.57cd
5	0	12.10b	4.669b	36.91d
10		17.32a	5.938a	36.54a
20		11.68b	3.059cd	33.97b
0	800	5.42d	0.848h	29.82de
5		10.83b	3.288cd	35.74a
10		17.45a	3.548c	35.68a
20		17.89a	3.005d	33.55b
0	1600	1.95ef	0.123I	25.27g
5		12.00b	1.453g	33.40b
10		5.27d	2.046ef	32.98b
20		2.79e	3.260cd	31.39c
0	2400	0.58fg	0.000I	17.20i
5		7.67c	0.687h	29.30e
10		2.41e	1.609fg	29.01e
20		2.52e	1.729efg	27.06f
0	3200	0.33g	0.000I	14.37j
5		0.48fg	0.085I	26.36fg
10		1.26efg	0.000I	26.74f
20		1.27efg	0.048I	22.74h
<b>Means</b>				
NaCl (0 mg kg <sup>-1</sup> )		13.09A	3.967A	34.40A
NaCl (800 mg kg <sup>-1</sup> )		12.90A	2.672B	33.70B
NaCl (1600 mg kg <sup>-1</sup> )		5.51B	1.721C	30.76C
NaCl (2400 mg kg <sup>-1</sup> )		3.30C	1.006D	25.64D
NaCl (3200 mg kg <sup>-1</sup> )		0.83D	0.033E	22.56E
Zn (0 mg kg <sup>-1</sup> )		3.91	0.634D	23.45 C
Zn (5 mg kg <sup>-1</sup> )		8.62A	2.036C	32.27 A
Zn (10 mg kg <sup>-1</sup> )		8.74A	2.628A	32.19A
Zn (20 mg kg <sup>-1</sup> )		7.23B	2.221B	29.74B
<b>Significance</b>				
NaCl		**	**	**
Zn		**	**	**
NaCl×zn		**	**	**

\*Means followed by the same letter (small letters for means and capital letters for means of rows and columns) are not significantly different at 5% level of probability using Tukey test. \*, \*\*Significant at p = 0.05 or 0.01, respectively

3200 mg kg<sup>-1</sup> soil), however, zinc especially at 5 and 10 mg kg<sup>-1</sup> soil diminished the negative effects of NaCl on these parameters. Present results are in agreement with those of Verma and Neue (1984). They showed that the application of Zn at rates as high as 10 mg kg<sup>-1</sup> soil increased the shoot height of rice under salinity conditions. At the first salinity level (Table 4), there is no significant difference between control and salt treated seedlings. The highest level of soil salinity (3200 mg kg<sup>-1</sup>) had the highest harmful effect on these parameters with or without Zn treatment, however, zinc treated plants had significantly higher relative stem diameter. Both the relative plant height and relative number of leaves were not increased by zinc application under the highest salinity level. There were significant differences between three levels of zinc application as compared with control (0 mg Zn kg<sup>-1</sup> soil). The differences in plants heights and their stem diameters at two levels of zinc (5 mg and 10 mg kg<sup>-1</sup> soil) were not significant.

As are shown in Table 5, salinity, zinc and salinity×zinc treatment effects on NAR, RGR, LAR and SLA were all significant. Low values in RGR in response to salinity are probably due to the growth characteristic of rootstock, because Badami rootstock grows slowly. The decrease in NAR with the increase in salinity could also be associated with a decrease in photosynthesis rates, an increase in respiration rates, or an increase in relative amount of non-photosynthetic tissues

Table 5: Effects of NaCl and Zn treatments on NAR (mg/mm<sup>2</sup>/day), RGR (mg/mg/day), LAR (mm<sup>2</sup>/mg) and SLA (mm<sup>2</sup>/mg) of pistachio seedlings

Treatments (mg kg <sup>-1</sup> )					
Zinc	NaCl	NAR	RGR	LAR	SLA
0	0	0.00533gh*	0.01031f	2.4748cdef	8.8623efgh
5		0.00650cde	0.01220b	2.7834abc	14.8756bcd
10		0.00768a	0.01350a	3.0476a	18.0408a
20		0.00544fgh	0.01146cd	2.6105bcd	10.2825ef
0	800	0.00500hi	0.00950g	2.1748fgh	8.4937efgh
5		0.00636cde	0.01220b	2.7735abc	14.6246cd
10		0.00755a	0.01348a	3.0102a	17.8986a
20		0.00535gh	0.01133cd	2.5713bcd	9.8357ef
0	1600	0.00450ij	0.00803i	2.0053hi	7.8442fgh
5		0.00603def	0.01174bcd	2.5528bcd	14.2537d
10		0.00720ab	0.01233b	2.8484ab	17.4162ab
20		0.00468ij	0.01050ef	2.3873defg	9.3345ef
0	2400	0.00358k	0.00703j	1.4695j	6.6857gh
5		0.00591efg	0.01108de	2.1907efgh	13.8752d
10		0.00692bc	0.01184bc	2.5223bcde	17.0011abc
20		0.00444ij	0.00920gh	2.0436hi	8.6342efgh
0	3200	0.00220l	0.00426k	1.0699k	6.0518h
5		0.00550fgh	0.00722j	1.7628ij	10.6475e
10		0.0065cd	0.00912gh	2.1058gh	13.4255d
20		0.00432j	0.00858hi	1.8604hi	8.1724efgh
Means					
NaCl (0 mg kg <sup>-1</sup> )		0.00624 A	0.01187A	2.7291A	13.0153A
NaCl (800 mg kg <sup>-1</sup> )		0.00606 A	0.01163A	2.6324A	12.7132AB
NaCl (1600 mg kg <sup>-1</sup> )		0.00560B	0.01065B	2.4485B	12.2122AB
NaCl 2400 mg kg <sup>-1</sup> )		0.00521C	0.00979C	2.0565C	11.5490B
NaCl 3200 mg kg <sup>-1</sup> )		0.00464D	0.00730D	1.6997D	9.5743C
Zn (0 mg kg <sup>-1</sup> )		0.00412D	0.00782D	1.8388C	7.5875D
Zn (5 mg kg <sup>-1</sup> )		0.00606B	0.01089B	2.4126B	13.6553B
Zn (10 mg kg <sup>-1</sup> )		0.00718A	0.01206A	2.7069A	16.7564A
Zn (20 mg kg <sup>-1</sup> )		0.00484C	0.01021C	2.2946B	9.2519C
Significance					
NaCl		**	**	**	**
Zn		**	**	**	**
NaCl×Zn		**	**	**	*

\*Means followed by the same letter (small letters for means and capital letters for means of rows and columns) are not significantly different at 5% level of probability using Tukey test. \*, \*\*Significant at p = 0.05 or 0.01, respectively

participating in respiration (Poorter, 1989). Consequently, for pistachio seedlings growing in saline conditions, NAR is the most important parameter reflecting differences in RGR, whereas LAR and SLA are of secondary importance. NAR may then be regarded as a reliable indicator of salinity stress and salinity tolerance in pistachio rootstocks. In this regard, the role of Zn in photosynthesis is said to be the maintenance of a high K concentration in guard cells, increasing carbonic anhydrase activity (Cakmak and Engels, 1999), increasing the demand of sink for phloem sap due to reduction of carbohydrates especially in phloem sap of source leaves that improves phloem sap export or increases sink demand, increasing the levels of IAA and protein synthesis (Cakmak *et al.*, 1989). Regarding zinc application, Table 4 shows that the vegetative growth characters of pistachio seedlings treated with zinc were greater than those treated with salt. Results also indicated that pistachio plants were more tolerant to salinity in the presence of zinc. Salinity reduced all growth parameters. However, zinc treatment reversed these salinity effects, especially at 10 mg kg<sup>-1</sup> soil at all levels of NaCl (Table 5). There was no difference between 0 and 800 mg NaCl kg<sup>-1</sup> soil treatments with respect to these parameters. For these parameters, there was a clear decline in their values with increase in salinity either with or without Zn treatment. It is interesting to note that zinc application could maintain the net assimilation rate, relative growth rate, leaf area ratio and specific leaf area values at high level and it seems that Zn-fertilizer could neutralize or strongly decline negative effects of NaCl.



Supplying plants with increasing amounts of NaCl up to 3200 mg kg<sup>-1</sup> soil progressively decreased the vegetative growth characters. These results are in agreement with those obtained by Osawa (1963), who reported that, salinity causes growth reduction due to both salt osmotic effect and to specific ion effect. Vygis *et al.* (1985) observed that, the disturbance of vital activity of plants during salt stress is associated with growth reduction due to the marked alteration in their metabolism and to the decrease in organic matter production. The decreases in shoot and root growth due to NaCl became less distinct when the growth of plants had already depressed by Zn deficiency. This indicated that under the Zn-deficient conditions, Zn deficiency was a greater limiting factor than NaCl toxicity in reducing growth. Similar results were also reported by Genc *et al.* (2005) in studies with wheat plants. When plants were adequately supplied with Zn (e.g., 5 and 10 mg kg<sup>-1</sup> soil), the reductions in leaf, shoot and root growth due to NaCl treatments were more evident at the higher (20 mg kg<sup>-1</sup> soil) than at the lower (5 and 10 mg kg<sup>-1</sup> soil) doses of Zn specially at the lower salinity concentrations and these effects were approximately similar at the higher NaCl concentrations.

Increase in soil salinity levels resulted in a marked decrease in plants zinc content. These results are similar to the observations made by El-Sherif *et al.* (1990), who reported that increasing soil salinity decrease the plants dry matter so does the zinc content. Zinc addition to the soil might enhance the salinity resistance of *pistacia vera* L. cv. Badami. Shukla and Mukhi (1985) reported that adding Zn to saline soil increases the vegetative growth parameters of sage plants compared with control (-Zn) which is perhaps related to the increase in Ca, Mg, K and Zn uptake. Marschner (1995) has reported that, zinc addition will help plants to overcome the harmful effects of soil salinity due to the role of zinc as a component of some important enzymes such as carbonic anhydrase, or as a regulatory for others. Zinc has an essential role in many metabolic activities. Soliman *et al.* (1999) showed that, zinc is required for photosynthesis and enhances shoot and root growth. Salama *et al.* (1996) and El-Fouly *et al.* (2001) reported that spraying micronutrient elements has been used to prevent growth disorders of crops under saline conditions. Also, Abou Hossein *et al.* (2002) showed positive effects of zinc on dry matter of both root and shoot. The application of Zn enhanced dry matter yield of barley plants. Aslam *et al.* (2000) demonstrated that fresh shoot weight of rice was increased by Zn application under saline conditions; which might be due to better utilization of nitrogen under saline conditions.

As photo-oxidative damage is common in plants exposed to some stresses such as salinity stress (Alscher *et al.*, 1997), the Zn nutritional status of plants under such conditions should become more crucial. Therefore, improvement in Zn nutritional status of plants is of prime importance in protecting plants from such environmental stresses.

In addition to leaf chlorosis and necrosis, decrease in leaf size and inhibition of both shoot elongation and growth are further specific morphological changes occurring in Zn-deficient plants under saline conditions. It is widely accepted that these morphological changes in Zn-deficient plants exposed to salinity stress are attributable to decreased levels of the growth hormone, indole-3-acetic acid (IAA) (Skoog, 1940; Marschner, 1995). Decrease in IAA levels due to Zn deficiency is more pronounced under salinity stress (Cakmak *et al.*, 1989; Domingo *et al.*, 1990).

Micronutrients play many important roles in plant nutrition and plant metabolism. For example, zinc is the component of many plant enzymes and acts as metal activator for others. In addition, organic matter, water status, texture and sorption capacity of the soil, also affect zinc nutrition of plants (Bergman, 1992). Welch *et al.* (1982) stated that Zn is necessary for root growth and cell membrane integrity. As suggested by Marschner and Cakmak (1986) and Parker *et al.* (1992), root cell membrane permeability is increased under Zn deficiency which might be related to the functions of Zn in cell membranes. From this point of view, external Zn concentrations could mitigate the adverse effect of NaCl by inhibiting Na and/or Cl uptake or translocation. Alpaslan *et al.* (1999) concluded that in the salt affected areas, zinc application could alleviate possible Na and Cl injury to the plants. Soil salinity may reduce Zn uptake due to stronger competition by salt cations at the root surface.

## CONCLUSION

Zn fertilization markedly increases pistachio biomass, shoot height, leaf number, stem diameter, net assimilation rate, relative growth rate, leaf area ratio and specific leaf area at all salinity levels. These growth indices are markedly reduced when the amount of Zn in media is below optimum levels under salinity conditions.

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