Australian Journal of Basic and Applied Sciences, 6(5): 54-61, 2012
ISSN 1991-8178

Effect of Water Amounts on Artichoke Productivity Irrigated with Brackish Water

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Abstract: The objective of this study was to determine the optimal water amount for globe artichoke irrigated with low quality (brackish) water. During the growing seasons 2008/2009 and 2009/2010, seed-propagated cultivar "Green Globe" was irrigated using different combination among three salinity levels, e.g., 1.5, 3.0 and 6.0 dS m^{-1} and three water amounts, e.g., 85, 100 and 115% of Class A pan evaporation equation. The obtained results indicate that increasing salinity levels caused significant reduction in vegetative growth characters and bud yield of artichoke plants. All vegetative growth characters, e.g., plant height, number of leaves per plant and leaf dry weight as well as bud yield components, e.g., total and marketable yields were gradually reduced by increasing salinity levels from 1.5 to 6.0 dS m^{-1}. Moreover, salinity reduced essential nutrients, e.g., K, Mg and Ca and increased harmful elements, e.g., Na and Cl in plant tissues, e.g., leaves and buds. Increasing water amounts positively affected vegetative growth characters of artichoke plants and increased artichoke productivity, e.g., total yield and marketable yield of buds. On the other hand, water use efficiency (WUE) as g marketable yield of buds per supplied water unit (L) was reduced with increasing water amount from 85 to 115% of Class A pan evaporation. The different water amounts slightly affected the content of essential nutrients based on the different nutrients (K, Mg and Ca) and different plant parts (leaves and buds). The harmful elements, e.g., Na and Cl were decreased in leaves and buds with increasing the amount of supplied water.

Key words: *Artichoke, Water amounts, Water use efficiency, Brackish water, EC.*

INTRODUCTION

The world human population is expected to reach 8.0 billion by 2025 (FAO, 2006). About 80 million people are being added to the population total each year, and 97% of the predicted population growth will take place in the developing countries, including Egypt. The developing countries, in particular, are confronted with severe food-security challenges. Food security is challenged by increasing food demand and threatened by declining water availability, where the world's water supply is fixed. Environmental stress and significant changes in climate on a global scale impact agriculture and consequently affect the world's food supply (FAO, 2001). Environmental stress is the primary cause of crop losses worldwide, reducing average yields for most major crops by more than 50% (Bray *et al.,* 2000). Increasing both salinity and temperature and reduced irrigation water availability are major limiting factors in sustaining and increasing plant productivity in many arid and semi-arid areas, where rainfall is normally lower than evapotranspiration.

Water shortage is one of the challenges facing Egypt, with a per capita water share of 860 m^3/year in 2003 and is expected to decrease to 582 m^3/year by the year 2025. Therefore, we have to put water on the top of the agenda for science and technology. The total agriculture land in Egypt is almost entirely dependent on irrigation. This should motivate us to find ways for saving water and use marginal waters, without significant reduction in yield to satisfy the high rates of population growth requirements. Accordingly, it is advised to evaluate plant production under highest water use efficiency (WUE) using modern irrigation techniques (Saleh, 2003; Saleh *et al.*, 2007). This may help to minimize water consumption, reduce the losses of irrigation water and increase cultivated area.

Artichoke productivity is strongly affected by the amount of irrigation water (Boari *et al.,* 2000; Garnica *et al.,* 2004; Macua *et al.,* 2005; Tarantino *et al.,* 2005; Saleh *et al.,* 2007). Saleh, 2003 estimated the actual crop evapotranspiration (ET_c) for local artichoke vegetatively propagated cultivar "Balady" in Egypt based on Class A pan evaporation equation using volumetrically lysimeters. The highest plant growth, development and maximal crop yield are obtained by optimal water application from 75 to 100% of class A pan evaporation. Water application according to 85% of Class A pan was quite enough for the local cultivar "Balady" in Egypt. Application of water at 100% Class A pan resulted in the best plant growth and bud yield with a good product quality for the seed-propagated cultivar "Green Globe" (Saleh *et al.*, 2007).

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In coastal and sub-coastal regions in the Mediterranean basin (artichoke's cultivation areas), the salinization of irrigation water is an increasingly concerning issue. In many irrigated areas, dwindling supplies of quality water for irrigation and increasing demand from other users are forcing farmers to use saline irrigation waters (Shani and Dudley, 2001). Although artichoke is placed in the moderately salt-tolerant category, especially during the vegetative stage (Francois, 1995; Saleh *et al.*, 2005), yield and bud quality are highly negatively affected by salinity (Francois *et al.*, 1991; Graifenberg *et al.*, 1993 & 1995; Vincenzo *et al.*, 2000; Saleh *et al.*, 2005). In such regions, the competition for scarce water resources among users will inevitably reduce the supplies of fresh water available for crop irrigation. Consequently, agriculture will increasingly be forced to utilize marginal waters such as brackish water. In despite of the knowledge that has been gained through the studies on water management for artichokes, e.g., methods, amounts, regimes and intervals of irrigation, essential studies are highly needed to determine the optimal water requirements for artichoke production under poorer quality water (brackish). Thus, artichoke plants (cv. Green Globe) were evaluated under different quantity and quality of irrigation water.

MATERIALS AND METHODS

Two filed experiments on artichoke plants irrigated with different combination of water quantity and water quality were conducted in new reclaimed lands (Birqash, Giza Governorate, Egypt) during the two successive cropping seasons of 2008/2009 and 2009/2010. The soil characteristics were sand 87.4%, silt 3.9%, clay 8.7%, pH 7.9 and dS m^{-1} 1.6 dS m^{-1}. Soil moisture at field capacity 19% and at wilting point 10% of soil dry weight. Eight-week old artichoke seedlings (cv. Green Globe) of good quality were transferred in the open field on August 1^{st} in both cultivation seasons. Before planting, the entire experimental field was well watered by furrow irrigation as recommended by Prados, 1989. After transplanting, all seedlings were first irrigated with fresh water (1.5 EC) for good plant establishment using drip irrigation system. Two weeks later, NaCl was added to the fresh water of the two saline treatments (brackish water), resulting in a final EC value of 3.0 and 6.0 dS m^{-1}.

The potential water for artichoke was calculated based on Class A pan evaporation equation. Water requirement was calculated by the following formulas according to Allen *et al.*, 1998:

$ET_0 = E_{pan} \times K_p$

$CU = ET_0 \times K_c$

$WR = CU \times L\%$

Where:

ET_o: Reference evapotranspiration. E_{pan}: Pan evaporation in mm.

K_p: Pan coefficient (constant, 0.85). CU: Water consumption.

L%:Leaching factor (1.25%). WR: Water requirement (L m^{-2}).

K_c: Crop coefficient (variable 0.4:1.6, depending on plant growth stage after Saleh, 2003 and Saleh *et al.*, 2007.

Different three water amounts (85, 100 and 115% of Class A pan evaporation) were applied daily. The total amounts of water supplied to plots receiving 85, 100 and 115% of Class A pan evaporation were 609, 716 and 823 L m^{-2}, respectively.

The experimental design was split-plot (two-factorial experiment) with three replications. The three salinity levels (1.5, 3.0 and 6.0 dS m^{-1}) were assigned to the main-plots (Factor A). While three water amounts (85, 100 and 115% of Class A pan evaporation) were randomized and occupied the sub-plots (Factor B). Plant spacing was 1.0 m in row 1.0 m apart (1.0 plant m^{-2}), each plot consisted of 30 plants. Before planting, 90 kg P_2O_5 ha^{-1} was soil-incorporated and 244 kg N ha^{-1} and 60 kg K_2O ha^{-1} were applied (Broadcast) during the plant growth stages. Other agricultural practices such as weed control, pest management and gibberellic acid (GA_3) application were followed according to Instructions lectures (1997) by the Ministry of Agriculture, Egypt.

Evaluated Parameters:

Vegetative growth characters, e.g., plant height (cm) and number of leaves per plant were recorded 60 and 120 days after transplanting. Leaf dry weight (g) was measured on representative samples of the 4^{th}-youngest leaf.

Total yield was recorded as weight of buds per plant, while the marketable yield per plant was calculated after exclusion of buds that had black spots (non-marketable). Water use efficiency (WUE, g l^{-1}), was calculated as g marketable yield per L water supplied. Also, the average weight of bud was calculated.

Representative samples were collected individually from the 4^{th}-youngest leaf and bud to determine the essential nutrients (K, Mg and Ca) and harmful elements (Na and Cl) in growing season 2009/2010. For chemical analyses, the plant samples were dried for 3 days in an oven at 70°C. The samples were ground. K, Mg, Ca and Na were determined by the flame AAS (VARIAN Spectra AA 100) after 6 hours ashing at 550°C and digested with concentrated HCl. Cl was determined by $Hg(NO_3)_2$ titration after extraction with distilled water.

Statistical Analysis:

The obtained data were statistically analyzed using CoStat software package (CoHort Software, 1986). The mean values were compared using Duncans's multiple range test at P<5% as reported by Gomez and Gomez (1984).

Results:

Vegetative Growth Characters:

Data presented in Table (1) exhibit the effect of different salinity levels, water amounts and their interaction on vegetative growth characters of artichoke plants during the growing seasons 2008/2009 and 2009/2010.

Results show that vegetative growth characters of artichoke plants as represented by plant height (cm), number of leaves per plant and leaf dry weight (g) at 60 and 120 days after transplanting statistically decreased by increasing salinity levels from 1.5 dS m^{-1} (fresh water) to 6.0 dS m^{-1} (brackish water) during both seasons (Table 1). These results are in agreement with that observed by Graifenberg *et al.,* 1993 & 1995; Francois, 1995; Vincenzo *et al.,* 2000; Saleh *et al.,* 2005 and Saleh, 2011.

Table 1: Effect of salinity levels and water amounts on vegetative growth characters of artichoke plants at 60 and 120 days after transplanting (DAT) during the growing seasons 2008/2009 and 2009/2010.

Treatments:		Plant height (cm)	Number of leaves/plant 60 DAT	Leaf dry weight (g)	Plant height (cm)	Number of leaves/plant 120 DAT	Leaf dry weight (g)
Salinity levels:				2008/2009			
Control (1.5 dS m^{-1})		54.9a	11.6a	11.7a	117.8a	20.3a	16.4a
3.0 dS m^{-1}		44.4b	10.3b	10.0b	100.7b	17.8b	13.7b
6.0 dS m^{-1}		36.8c	8.8c	8.6c	88.2c	15.4c	10.7c
Water amounts:							
85% of pan		41.1c	9.6c	9.8a	99.6c	17.1b	13.0b
100% of pan		45.7b	10.2b	10.1a	102.4b	17.8b	13.3b
115% of pan		49.3a	10.9a	10.4a	104.7a	18.7a	14.4a
Interaction:							
1.5 dS m^{-1}	85% pan	49.3c	10.7a	11.3a	115.3a	19.7a	15.3b
	100% pan	55.3b	11.7a	11.7a	118.0a	20.3a	16.3b
	115% pan	60.0a	12.3a	12.3a	120.0a	21.0a	17.7a
3.0 dS m^{-1}	85% pan	39.3e	9.7a	9.7a	98.0a	17.0a	13.7c
	100% pan	45.3d	10.3a	10.0a	101.3a	17.7a	13.0c
	115% pan	48.7c	11.0a	10.3a	102.7a	18.7a	14.3bc
6.0 dS m^{-1}	85% pan	34.7f	8.3a	8.3a	85.3a	14.7a	10.0e
	100% pan	36.3f	8.7a	8.7a	88.0a	15.3a	10.7de
	115% pan	39.3e	9.3a	8.7a	91.0a	16.3a	11.3d
Salinity levels:				2009/2010			
Control (1.5 dS m^{-1})		56.8a	12.4a	12.7a	120.4a	21.9a	17.6a
3.0 dS m^{-1}		48.1b	11.0b	11.2b	98.9b	19.1b	15.3b
6.0 dS m^{-1}		41.4c	10.3c	10.2c	90.3c	16.7c	12.1c
Water amounts:							
85% of pan		45.2c	10.4b	10.9b	101.1b	18.6b	14.3b
100% of pan		49.0b	11.3a	11.4ab	103.6ab	19.1ab	14.8b
115% of pan		52.1a	12.0a	11.8a	105.0a	20.0a	15.8a
Interaction:							
1.5 dS m^{-1}	85% pan	51.7c	11.3a	12.3a	118.3a	21.0a	16.7a
	100% pan	56.8b	12.7a	12.7a	120.7a	22.0a	17.3a
	115% pan	62.0a	13.3a	13.0a	122.3a	22.7a	18.7a
3.0 dS m^{-1}	85% pan	43.7d	10.3a	10.7a	96.7a	18.7a	15.0a
	100% pan	49.0c	11.0a	11.3a	99.3a	19.0a	15.3a
	115% pan	51.7c	11.7a	11.7a	100.7a	19.7a	15.7a
6.0 dS m^{-1}	85% pan	40.3e	9.7a	9.7a	88.3a	16.0a	11.3a
	100% pan	41.3de	10.3a	10.3a	90.7a	16.3a	12.0a
	115% pan	42.7d	11.0a	10.7a	92.0a	17.7a	13.0a

Means within each column and factor followed by the same letter are not significantly different at *P*<5%.

Increasing water amounts positively affected vegetative growth characters of artichoke plants. The obtained results as assessed at 60 and 120 days after transplanting reveal that plant height (cm), number of leaves per plant and leaf dry weight (g) were generally increased progressively with increasing the amount of supplied water from 85% to 115% of Class A pan evaporation in both seasons (Table 1). The increase in leaf dry weight (g) was not enough to be significant at 60 days after transplanting during the first growing season (2008/2009).

These obtained results are in good accordance with which reported by Saleh, 2003; Garnica *et al.,* 2004 and Saleh *et al.,* 2007.

Concerning the interaction effects of salinity levels and water amounts, application of the highest water amount (115%) as fresh water (1.5 dS m^{-1}) resulted in the highest vegetative growth values, although these increases in vegetative growth characters sometimes were not statistically significant. While, application the lowest water amount (85%) as brackish water (6.0 dS m^{-1}) resulted in the lowest vegetative growth characters during the growing seasons 2008/2009 and 2009/2010 (Table 1).

Bud Yield and Bud Weight:

The results presented in Table 2 depict the effect of different salinity levels, water amounts and their interaction on bud yield of artichoke plants during the growing seasons 2008/2009 and 2009/2010.

Application of brackish water at both salinity levels, e.g., 3.0 and 6.0 dS m^{-1} to artichoke plants reduced bud yield and its components compared to application of fresh water (1.5 dS m^{-1}) as control treatment (Table 2). The reduction in total yield of buds per plant was around 19%, while the reduction in marketable yield reached to 25% due to salinity treatment of 3.0 dS m^{-1} compared to the non-saline control. Salinity treatment of 6.0 dS m^{-1} reduced total yield of buds by 33% and marketable yield by 45%. The mean weight of bud (g) and WUE as g yield of marketable buds per L supplied water gradually decreased by increasing salinity levels from 3.0 dS m^{-1} to 6.0 dS m^{-1} compared to fresh water treatment (Table 2). A similar magnitude for the decrease of bud yield under saline conditions was obtained by Francois *et al.,* 1991; Graifenberg *et al.,* 1993 & 1995; Francois, 1995; Saleh, 2003; Saleh *et al.,* 2005 and Boari *et al.,* 2012.

Table 2: Effect of salinity levels and water amounts on bud yield and water use efficiency (WUE) of artichoke plants during the growing seasons 2008/2009 and 2009/2010.

Treatments:		Total yield (g/plant)	Marketable yield (g/plant)	Mean weight of bud (g)	WUE (g L^{-1})
Salinity levels:		2008/2009			
Control (1.5 dS m^{-1})		4652a	4244a	287a	6.01a
3.0 dS m^{-1}		3772b	3178b	252b	4.49b
6.0 dS m^{-1}		3085c	2329c	222c	3.28c
Water amounts:					
85% of pan		3723c	3141c	239c	5.16a
100% of pan		3866b	3250b	258b	4.54b
115% of pan		3920a	3359a	264a	4.08c
Interaction:					
1.5 dS m^{-1}	85% pan	4609a	4219a	277b	6.93a
	100% pan	4662a	4247a	289a	5.93b
	115% pan	4685a	4265a	295a	5.18c
3.0 dS m^{-1}	85% pan	3596c	3039c	235d	4.99c
	100% pan	3814b	3208b	257c	4.48d
	115% pan	3906b	3286b	265c	3.99e
6.0 dS m^{-1}	85% pan	2964e	2164f	205e	3.55ef
	100% pan	3121d	2296e	228d	3.21ef
	115% pan	3170d	2528d	233d	3.07f
Salinity levels:		2009/2010			
Control (1.5 dS m^{-1})		4635a	4234a	286a	6.00a
3.0 dS m^{-1}		3755b	3194b	249b	4.51b
6.0 dS m^{-1}		3096c	2342c	217c	3.29c
Water amounts:					
85% of pan		3679c	3149c	233c	5.17a
100% of pan		3807b	3232b	252b	4.51b
115% of pan		4001a	3389a	267a	4.12c
Interaction:					
1.5 dS m^{-1}	85% pan	4533b	4206a	273b	6.91a
	100% pan	4611b	4201a	284b	5.87b
	115% pan	4762a	4296a	300a	5.22c
3.0 dS m^{-1}	85% pan	3559e	3092c	228e	5.09c
	100% pan	3727d	3187c	248d	4.45d
	115% pan	3980c	3302b	271c	4.01e
6.0 dS m^{-1}	85% pan	2945g	2149f	199f	3.53f
	100% pan	3082fg	2307e	224e	3.22g
	115% pan	3261f	2569d	229e	3.12g

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$.

The results show that application of 115% Class A pan evaporation to artichoke plants resulted in the highest total yield (3920 - 4001 g) and marketable yield (3359 - 3389 g) of buds per plant in both growing seasons, respectively (Table 2). While artichoke plants irrigated with 85% Class A pan evaporation resulted in the lowest total yield (3723 - 3679 g) and marketable yield (3141 - 3149 g) of buds per plant in both growing seasons, respectively. The mean weight of bud (g) was increased from 239 - 233 g to 264 - 267 g due to the increase of the amount supplied water from 85% to 115% Class A pan evaporation during the growing seasons 2008/2009 and 2009/2010, respectively (Table 2). A similar trend to increase bud yield with increasing irrigation water was reported by many authors (Litrico *et al.*, 1998; Saleh, 2003; Garnica *et al.*, 2004; Macua *et al.*, 2005; Saleh *et al.*, 2007; Leskovar, *et al.*, 2011; Boari *et al.*, 2012). Concerning the water use efficiency (WUE), it is evident that the quantities of application water adversely affected the WUE calculated based on marketable buds yield, where the reduction in watering amounts from 115 to 85% Class A pan evaporation resulted in gradual increases in WUE from 4.08 - 4.12 to 5.16 - 5.17 as g yield of buds per L supplied water (Table 2). These results are in accordance with those obtained by Boari *et al.*, 2000; Gibberd *et al.*, 2003; Saleh, 2003; Saleh *et al.*, 2007.

With regard to the interaction effects of salinity levels and water amounts, application of the highest water amount (115%) as fresh water (1.5 dS m^{-1}) to artichoke plants resulted in the highest total and marketable yield of buds as well as bud weight, while the lowest values were obtained by application of the lowest water amount (85%) as brackish water (6.0 dS m^{-1}). On the other hand, WUE was increased by irrigation with fresh water (1.5 dS m^{-1}) at the lowest amount (85%) and was decreased by irrigation with brackish water (6.0 dS m^{-1}) at the highest amount (115%) during the growing seasons 2008/2009 and 2009/2010 (Table 2).

Essential Nutrients and Harmful Elements:

Essential nutrients, e.g., K, Mg and Ca and harmful elements, e.g., Na and Cl in different artichoke parts, e.g., leaves and buds as affected by salinity levels and water amounts and their interactions are presented in Table 3.

Table 3: Effect of salinity levels and water amounts on nutrient contents of different artichoke parts (leaves and buds) during the growing season 2009/2010.

Treatments:		K	Mg	Ca	Na	Cl
		(% dry weight)				
Salinity levels:		Leaves				
Control (1.5 dS m^{-1})		4.47a	0.35a	2.11a	0.69c	1.12c
3.0 dS m^{-1}		4.24b	0.25b	1.74b	3.71b	3.67b
6.0 dS m^{-1}		3.22c	0.20c	1.13c	4.62a	5.00a
Water amounts:						
85% of pan		4.01a	0.25b	1.58b	3.06a	3.38a
100% of pan		3.98a	0.28a	1.67a	3.02a	3.24b
115% of pan		3.95a	0.29a	1.72a	2.94b	3.17c
Interaction:						
1.5 dS m^{-1}	85% pan	4.53a	0.33a	2.02a	0.70e	1.15f
	100% pan	4.45a	0.36a	2.11a	0.69e	1.08f
	115% pan	4.43a	0.37a	2.19a	0.67e	1.12f
3.0 dS m^{-1}	85% pan	4.21b	0.23a	1.69a	3.77c	3.88c
	100% pan	4.26b	0.26a	1.75a	3.72cd	3.65d
	115% pan	4.25b	0.27a	1.78a	3.63d	3.48e
6.0 dS m^{-1}	85% pan	3.28c	0.19a	1.05a	4.70a	5.11a
	100% pan	3.22cd	0.20a	1.15a	4.65a	4.98b
	115% pan	3.16d	0.22a	1.20a	4.51b	4.92b
Salinity levels:		Buds				
Control (1.5 dS m^{-1})		4.21a	0.20a	0.55a	0.59c	0.78c
3.0 dS m^{-1}		3.69b	0.18b	0.39b	1.77b	3.19b
6.0 dS m^{-1}		3.08c	0.16c	0.29c	2.61a	4.29a
Water amounts:						
85% of pan		3.70a	0.17a	0.36b	1.71a	2.84a
100% of pan		3.66ab	0.18a	0.42a	1.66b	2.77a
115% of pan		3.63b	0.19a	0.44a	1.60c	2.65b
Interaction:						
1.5 dS m^{-1}	85% pan	4.25a	0.19a	0.52a	0.60e	0.81e
	100% pan	4.19a	0.20a	0.55a	0.59e	0.79e
	115% pan	4.20a	0.21a	0.58a	0.58e	0.74e
3.0 dS m^{-1}	85% pan	3.75a	0.17a	0.33a	1.82c	3.27c
	100% pan	3.69a	0.18a	0.41a	1.80c	3.19cd
	115% pan	3.64a	0.18a	0.43a	1.69d	3.11d
6.0 dS m^{-1}	85% pan	3.10a	0.15a	0.24a	2.70a	4.43a
	100% pan	3.11a	0.16a	0.31a	2.59b	4.34a
	115% pan	3.04a	0.17a	0.32a	2.53b	4.09b

Means within each column and factor followed by the same letter are not significantly different at $P<5\%$.

The obtained results indicate that the content of K, Mg and Ca in the leaves and buds tissues were reduced with increasing salinity levels from 1.5 dS m^{-1} (fresh water) to 6.0 dS m^{-1} (brackish water). On the contrary, Na and Cl were gradually increased in both leaves and buds with increasing the salinity levels from 3.0 dS m^{-1} to 6.0 dS m^{-1} compared to fresh water treatment (Table 3). These data are in agreement with the findings of Francois, 1995; Graifenberg *et al.*, 1995, Saleh, 2003; Saleh, 2011.

Different water amounts, e.g., 85, 100 and 115% of Class A pan evaporation slightly affected the content of essential nutrients based on the different nutrients (K, Mg and Ca) and different plant parts (leaves and buds), where the effects did not take the same trend (Table 3). The content of K in the leaf tissues remained unchanged by all water amounts treatments and slightly tended to decrease in bud tissues of artichoke plants with increasing the amount of supplied water from 85% to 115% Class A pan evaporation (Table 3). The content of Mg in the leaf tissues was increased with increasing the amount of supplied water from 85% to 100% Class A pan evaporation, and was remaining almost constant with further increase of the amount water (115% Class A pan evaporation), while, no significant change in Mg content in bud tissues due to different water amounts was detected. The content of Ca in the leaves and buds tissues were increased with increasing the amount of supplied water from 85% to 100% Class A pan evaporation, and was remaining almost constant with further increase of the amount water (115% Class A pan evaporation). Similar results were observed by Saleh, 2003. The harmful elements, e.g., Na and Cl were decreased in both studied artichoke tissues, e.g., leaves and buds with increasing the amount of supplied water from 85% to 115% Class A pan evaporation (Table 3).

Concerning the interaction effects of salinity levels and water amounts, application of the highest water amount (115%) as fresh water (1.5 dS m^{-1}) generally resulted in the highest content of essential nutrients, e.g., K, Mg and Ca in different plant parts, e.g., leaves and buds, although no significant different among all water amounts as fresh water category (Table 3). The lowest water amount (85%) as brackish water (6.0 dS m^{-1}) generally resulted in the lowest content of those essential nutrients. On the other hand, the highest water amount (115%) as fresh water (1.5 dS m^{-1}) reduced the harmful elements, e.g., Na and Cl in leaves and bud tissues, where the lowest water amount (85%) as brackish water (6.0 dS m^{-1}) increased the content of those elements (Table 3).

Discussion:

The adverse effect of increasing salinity on plant growth was possibly mainly due to the low (more negative) osmotic potential of the nutrient solution. Also, an osmotic shock in the root cells may have occurred directly after exposure to the highest dS m^{-1} (Munns, 2002). Young roots, especially the root hair zone are most important for nutrient and water uptake and subsequently for stand establishment. High salt concentrations resulting in low water potentials reduce root elongation of many crops (Kafkafi, 1996). The decrease in water uptake is strongly and linearly correlated to dS m^{-1} (Dalton *et al.*, 1997). At high salinity level, toxicity reactions may have contributed to growth depression (Munns, 2002). This assumption is supported by more pronounced reduction in plant growth under the highest salinity level (6.0 dS m^{-1}). Yield reduction was mainly attributed to the negative effect of salinity on the weight of buds rather than to the number of buds per plant. This may be explained as a main result of saline adverse effects on plant growth and assimilation rate, accordingly, decreasing dry matter accumulation. Tarantino et al. (2000) also found that the bud size was reduced, while the percentage of dry matter and fiber content increased in the buds. The even stronger reduction in marketable buds was due to marginal leaf necrosis, which was also experienced by Francois *et al*. (1991) and Graifenberg *et al*. (1995) at similar dS m^{-1} levels. These results demonstrate that artichoke irrigated with saline water needs watering more frequently, mainly to preserve buds weight yield (Boari *et al.*, 2012). To reduce damage caused by irrigation with saline water, one technique consists of favouring leaching of salts supplied through irrigation during irrigation season by applying greater watering volumes than those required to bring the soil layer explored by roots to field capacity (Ayers and Westcot, 1985). The decrease of K, Mg and Ca in plant tissues was most likely due to the antagonism between Na and K, Mg or Ca at the sites of uptake in the roots and the effect of Na on the K, Mg and Ca transport in the xylem (Grattan and Grieve, 1999; Cramer, 2002). In addition, the competitive uptake of harmful elements (Na and Cl) against essential nutrients (K, Mg and Ca), may also have contributed to limited vegetative growth, causes drops in yield due to osmotic, toxic and nutritional damage to the crop. This common effect deriving from uptake competition between harmful elements and essential nutrients at the roots was also observed by Graifenberg *et al.*, 1995; Saleh *et al.*, 2005.

The enhancing effect of increasing irrigation amounts on plant growth can be explained by the fact that water is a major constituent of growing plant tissues and many biochemical processes. Water has a crucial role in the process of photosynthesis and acts as a translocation agent of organic and mineral constituents. Hence, the size and turgor of the cells increase, resulting in increases of vegetative growth. The beneficial effect of applied water at 115% Class A pan evaporation on plant vegetative growth resulted in more accumulation of dry matter which is possibly the main reason for bud yield increases and improvement of bud weight. A similar trend to increase bud yield with increasing irrigation water was reported by many authors (Litrico *et al.*, 1998;

Saleh, 2003; Garnica *et al.,* 2004; Macua *et al.,* 2005; Saleh *et al.,* 2007; Leskovar, *et al.,* 2011; Boari *et al.,* 2012). But, Foti *et al.* (2005) found slight reduction (6%) in bud yield by supplying water with 50% of evapotranspiration compared to 100% treatment. However, 150% of evapotranspiration showed an increase in the number of buds compared to 100% (Tarantino *et al.,* 2005). Water use efficiency was reduced with increasing salinity levels and/or water amounts. It means that the increases in supplied water unit (L) were not reflected by the same levels of increases in the buds yield unit (g) according to the law of diminishing return benefit (gain). These results are in accordance with those obtained by Boari *et al.,* 2000; Gibberd *et al.,* 2003; Saleh, 2003; Saleh *et al.,* 2007. We should not forget that irrigation water means an additional cost and could influence on its profitability (Garnica *et al.,* 2004). Several researchers (Shani and Dudley, 2001; Katerji *et al.,* 2003) have indicated that when saline waters are used for irrigation much attention should be given to minimize root-zoon salinity. Other has indicated the need of selection and use of appropriate irrigation systems and practices that will supply just sufficient quantity of water to root-zone to meet the evaporative demand and minimize salt accumulation in the root-zone (Munns, 2002). Irrigation turn has stated one of the most important factors in crop management when using saline water for irrigation (Pereira *et al.,* 2009). Saline water requires more frequent irrigation than for fresh water because salts in the water and the soil increase the osmotic potential of the soil water, which makes water uptake by the plant roots more difficult (Boari *et al.,* 2012).

Conculosion:

Increasing salinity levels caused significant reduction in vegetative growth characters and yield of artichokes. Salinity reduced essential nutrients and increased harmful elements in leaves and buds. Increasing water amounts positively affected vegetative growth characters and increased artichoke productivity. Water use efficiency was reduced with increasing salinity level and/or water amount. We have to know excess water is an additional cost and could influence on its profitability. At new reclaimed lands, where fresh water is limited, we can recommend to apply extra brackish water for leaching harmful elements from root-zone.

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