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Salinity Duration and Concentration Affect Fruit Yield and Quality, and Growth and Mineral Composition of Melon Plants Grown in Perlite

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***Abstract*. The shortage of good quality water in semiarid zones necessitates the use of saline water for irrigation. In order to simulate the usage of brackish irrigation water in greenhouse melon (*Cucumis melo* L. cv. Galia) culture in perlite, plants were supplied with nutrient solutions containing 0 (control), 20, 40, and 60 mM NaCl applied at four different times. Treatments were applied during early vegetative growth [14 days after transplanting (DAT)], beginning of flowering (37 DAT), beginning of fruit set (56 DAT), and beginning of fruit ripening (71 DAT). All vegetative and fruit yield parameters were significantly reduced when salinization was started 14 DAT. This inhibitory effect of salinity was progressively lessened when salinity was imposed at later dates. This suggests that the response of melons to salinity depends on the duration of exposure to saline water. Salinity treatments increased fruit reducing sugars, acidity, and total soluble solids. Fruit yield reduction at each salinization time was correlated with salinity levels, but there was some evidence of a nutrient imbalance, since leaf concentrations of N-NO_3, and especially K, were low at higher salinities. These results indicate that brackish waters can be used for growing melon with minimum yield losses if concentration and duration of exposure are carefully monitored.**

Melon is an important horticultural crop widely cultivated in southern Spain and other semiarid regions of the world. The market demand for melons of high quality throughout the season has increased production of this crop using greenhouse soilless conditions. For many greenhouse growers, good quality water is scarce, which forces them to use brackish waters to prepare nutrient solutions for irrigation.

Previous research, focused on germination, vegetative growth, or fruit yield under soil or greenhouse conditions, has demonstrated considerable genotypic variation in the response of melon to salinity (Mangal et al. 1988; Mendlinger, 1994; Mendlinger and Pasternak, 1992a, 1992b; Nerson and Paris, 1984; Nukaya et al., 1980; Shannon et al., 1984). Salt tolerance is affected by several factors, including the growth stage at the time of exposure, duration of exposure, environmental conditions, and type of substrate (Adams, 1991; Kuehny and Morales, 1998; Maas and Hoffman, 1977). Therefore, most results are not applicable to soilless culture in the greenhouse.

Physical properties of the substrate chosen may influence crop production and fruit quality. Perlite is a common growing medium for the cultivation of melon in commercial greenhouses in Spain. In the present study, therefore, we examined the response of the melon cultivar Galia grown in perlite to various salinity levels. The objective was to determine how different levels of salinity in the irrigation solution, applied at different times, affect vegetative growth, fruit yield, fruit quality, and leaf mineral composition.

Materials and Methods

Plant material and culture. Uniform muskmelon plants, cv. Galia, obtained from a commercial nursery, were grown in 1.2-m-long perlite-filled bags in a greenhouse equipped with a computer-regulated drip irrigation system under controlled environmental conditions. During the experiment, the day temperature was maintained at 20 to 30 ºC and the night temperature was never lower than 15 ºC. The relative humidity was ≥55% throughout the day, and ≥75% at night. The plants were transplanted on 10 Mar. 1997, and irrigated with a basic nutrient solution (pH 5.6) of the following macronutrient composition (mmol): NO_3^-, 14; $H_2PO_4^-$, 1.5; SO_4^{2-}, 1; Ca^{2+}, 4; K^+, 7.5; Mg^{2+}, 1. Micronutrient concentrations were ($mg \cdot L^{-1}$): Fe, 1.0; Mn, 0.5; Zn, 0.5; B, 0.25; Cu, 0.02; Mo, 0.01. The plants were irrigated according to the demand detected in the appropriate trays. Two bags of perlite for each treatment were placed on a demand tray, which had two electrodes for controlling the level of the solution. When the plants transpired, the water level dropped, which was detected by the electrodes, initiating the irrigation. The irrigation stopped when the level of water in the tray returned to the initial level. During the experiment, a beehive containing bumblebees (*Bombus terrestris* L.) was maintained in the greenhouse to enhance pollination.

Treatments applied. The experimental design consisted of randomized blocks with each block containing three perlite bags per treatment with six plants per bag. The salinity treatments consisted of four levels (2, 4, 6, and 8 $dS \cdot m^{-1}$) in the irrigation solution. The three highest levels were achieved by adding NaCl to the basic nutrient solution (2 $dS \cdot m^{-1}$). The three highest salinity levels were applied at four different times: 14 d after transplanting (DAT); 37 DAT (start of flowering of the first cluster, plants 0.8–1 m high); 56 DAT (start of fruit set), and 71 DAT (start of fruit ripening). Thus, there were 12 treatments (three salinity levels × four times) plus the control.

Data recorded. The total length of the main stem, number of internodes, length of the internode above node 40, stem diameter at 1 m height, and shoot biomass were recorded at the end of the experiment. The uppermost, fully expanded leaves were sampled 67 (May) and 114 DAT (July) and were oven-dried at 65 ºC for 48 h. Chemical analyses of leaf samples were carried out after digestion with nitric and perchloric acids (2:1). Levels of Na, K, Ca, and Mg were determined by atomic absorption spectrometry, and P by the molybdenum blue method (Murphy and Rieley, 1962). Chloride and N-NO_3 were extracted from 0.1 g of ground material with 50 mL of deionized water. Total nitrogen (N_t) was measured by a semimicro Kjeldahl method. Chloride was measured by electrometric titration with a Corning Chloride Analyzer 926 (Corning Ltd., Hastead, Essex, England), according to the method of Guilliam (1971). N-NO_3 was determined by the difference between absorbances at 210 and 270 nm in a spectrophotometer (Rand et al., 1975).

Ripe fruits were harvested weekly from 2 June to 4 July. Fruits of each individual plant were counted and weighed. Quality constituents were determined on filtrates of blended samples. Total soluble solids (TSS) were evaluated in an Atago N1 refractometer (Atago Co. Ltd., Tokyo), titratable acids were measured with 0.1 N NaOH and reducing sugars by the anthrone method (Hewitt, 1958). Before destructive analyses of the fruit, firmness was determined, after taking out three discs from the skin surface in the equatorial area, using a Bertuzzi FT011 penetrometer (Fruit Tester, Alfonsine, Italy), fitted with an 8-mm-diameter probe. Peel and pulp thickness were also measured.

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Data analysis. Data for vegetative and fruit yield parameters, fruit quality constituents, and leaf mineral composition were subjected to analysis of variance.

Results

Vegetative growth. In general, vegetative growth was reduced as salinity increased, only when treatment began 14 or 37 DAT (Table 1). This resulted in significant salinity level × salinization time interaction. The number of internodes on the main stem was reduced only at the higher salt concentration, and them only when treatment began 14 DAT. Effects on the length of the internode distal to node 40 were evident when treatment began 14, 37, or 56 DAT, but not 71 DAT.

Fruit yield components. Both fruit yield and number were significantly affected by salinity level, salinization time, and their interaction (Table 2). The effects of salinity levels were more severe when salts were applied at earlier growth stages. Reductions in yields of marketable fruit of plants exposed to 8 dS·m^{-1}, relative to the control plants, ranged from 56% when salinization was initiated 14 DAT to 16% when salt was applied 71 DAT. Yield reduction was associated more with fruit number (reduced 46%) than with the weight per fruit (reduced 17%). However, treatments begun 71 DAT decreased fruit yield mainly because of reductions in individual fruit weight. These responses were even more evident from regression analyses of relative fruit yield as a function of salt concentration at each of the four salinization times (Fig. 1). Despite the use of only four salinity levels, all correlation coefficients were significant. In all four linear regressions, the slope decreased as salinization was delayed, thus indicating that under these conditions, a delay in exposure to salinity stress lessened its effect on fruit yield.

Fruit quality. Quality components of melon fruit were significantly affected by salinity level, but not by time of salt application (Table 3). Titratable acidity (expressed in g citric acid per 100 mL of juice), TSS, electrical conductivity (expressed in dS·m^{-1}), and the content of reducing sugars (expressed in mg·L^{-1} of juice) increased (except for TSS at 71 DAT), whereas pH decreased, with increasing salinity. Pulp thickness was significantly reduced by increased salinity level, but the response was not systematically related to the time of exposure to salinity treatments. Fruit firmness was significantly affected by both salinity levels and time of the salt application. Firmness was higher at 37 than at 51 or 71 DAT.

Mineral composition of leaf tissue. Leaf concentrations of N_t, N-NO_3, and K were higher on 16 May, and Cl, Na, and Ca were higher on 2 July; whereas P and Mg concentrations tended to remain constant (Table 4). Leaf Cl concentrations increased with each increase in salinity level in both samplings, whereas leaf Na concentration increased when salinity level increased from 2 to 4 dS·m^{-1}. No clear effect of time of exposure to salinity on leaf Na and Cl concentrations was found. The concentrations of Na and Cl in the leaves on 16 May, but not

Table 1. Effects of water salinity level and time of application on vegetative responses of 'Galia' melon.

Salinization time (DAT)	Salinity level (dS·m^{-1})	Fresh biomass of shoot (g/plant)	Length of main stem (m)	Diam of main stem at 1 m high (mm)	No. of internodes on main stem	Length of internode above node 40 (cm)
14	2	1277	4.8	10.2	60	7.6
	4	1250	4.5	10.0	66	7.8
	6	1028	3.0	8.3	60	5.9
	8	688	2.8	7.5	51	3.5
	Mean	988	3.4	8.6	59	5.7
37	4	1170	3.8	9.8	55	6.5
	6	990	3.1	9.4	44	4.6
	8	848	2.4	8.8	54	4.4
	Mean	1002	3.1	9.3	51	5.2
56	4	1173	4.4	10.1	58	8.7
	6	1103	3.9	10.5	59	6.1
	8	1237	3.6	10.4	51	6.6
	Mean	1171	4.0	10.3	56	7.1
71	4	1180	4.3	9.8	59	8.6
	6	1149	3.6	9.4	56	8.5
	8	1126	3.8	9.9	56	8.0
	Mean	1151	3.9	9.7	57	8.4
Mean	4	1193	4.2	9.9	59	7.9
	6	1067	3.4	9.4	55	6.3
	8	974	3.1	9.1	53	5.6
ANOVA						
Salinity level		19.5***	70.4***	18.7***	19.5***	11.1***
Salinization time		4.6**	8.7**	11.3***	4.7**	14.4***
Salinity × time		3.3**	3.9**	3.7**	3.4**	2.6*

*,**,***Significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 2. Effects of water salinity level and time of application on fruit yield parameters of 'Galia' melon.

Salinization time	Salinity level	Yield (kg·m^{-2})		No. fruits/m^2		Wt per marketable fruit
(DAT)	(dS·m^{-1})	Total	Marketable	Total	Marketable	(g)
14	2	4.62	4.40	5.70	5.16	853
	4	3.95	3.71	5.25	4.54	816
	6	2.84	2.62	4.13	3.46	759
	8	2.34	1.93	4.00	2.88	670
	Mean	3.04	2.75	4.46	3.63	748
37	4	4.16	3.79	5.67	4.67	813
	6	3.58	3.38	5.15	4.47	758
	8	3.01	2.23	5.25	3.27	681
	Mean	3.58	3.13	5.36	4.14	751
56	4	3.93	3.86	5.21	4.56	846
	6	4.36	3.70	6.40	4.78	776
	8	3.80	3.39	6.35	4.62	733
	Mean	4.03	3.65	5.99	4.65	785
71	4	4.11	4.02	5.55	5.02	801
	6	4.23	3.98	5.88	5.07	769
	8	3.79	3.68	6.15	5.03	731
	Mean	4.04	3.89	5.86	5.04	767
	4	4.04	3.85	5.42	4.70	819
	6	3.75	3.42	5.39	4.45	766
	8	3.24	2.81	5.44	3.95	704
ANOVA						
Salinity level		33.4***	56.5***	1.6^{NS}	28.0***	27.8***
Salinization time		11.9***	19.4***	16.3***	25.2***	1.6^{NS}
Salinity × time		4.6**	5.4**	5.7**	7.2**	0.4^{NS}

^{NS,*,**,***}Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

on 2 July, were negatively correlated with fruit yield (r = –0.69* and –0.72*, respectively). Leaf N-NO_3 decreased from 0.96% to 0.74% in the first sampling (16 May) and from 0.71% to 0.40% in the second (2 July) as salinity increased from 2 to 8 dS·m^{-1}. The negative linear relationships between Cl and N-NO_3 concentrations in leaves were significant on both sampling dates (r = –0.78** and –0.83***, respectively). Leaf K decreased significantly with salinity in both samplings, but especially so in the second, when salinization began 14 DAT. Leaf concentrations of P, Ca, and Mg were not systematically related to salinity in either sampling.

Discussion

Almost all growth and fruit yield parameters of melon plants growing under greenhouse conditions with perlite as substrate were significantly affected by both the salinity concentrations in the irrigation solution and the time of exposure to salt. There were significant interactions between salinity levels and time of exposure to salt. Vegetative growth and fruit yield were more reduced by salinity stress as the time of exposure to salinity increased.

As salinity imposition was delayed, marketable fruit yield increased at each level of salinity (Table 2). For example, at 4 dS·m^{-1} the marketable fruit for the 37 DAT treatment increased by 2% with respect to the 14 DAT treatment, whereas at 6 dS·m^{-1} the increase was 22%. Thus, the 6 dS·m^{-1} treatment can be applied at 37 DAT, or the 8 dS·m^{-1} at 56 DAT, without appreciable fruit yield reduction. When yield was plotted against salinity level for each of the salinization times, the 14 DAT treatment had the steepest slope. This suggests that response of melon to salt is dependent on the time of exposure, which is in agreement with Shannon et al. (1984).

Increasing the salinity level induced changes in the two yield parameters; fruit number and mean fruit yield, although the relative effects depended on the time of exposure. When the salinity level increased from 2 to 8 dS·m^{-1} and commenced 14 DAT, marketable fruit yield reduction resulted primarily from reductions in the number of fruits (–44%) rather than in mean fruit weight (–21%). This suggests that salinity reduced fruit yield by aborting flowers and/or fruits and reducing fruit size. On the contrary, when the same salinity levels were imposed at 56 or 71 DAT, the number of fruits, both total and marketable, were unaffected or only marginally influenced; thus the reduction in mean fruit weight was the cause of yield reduction. Previous work has generally reported that salinity reduced yield primarily by reducing mean fruit weight (Mendlinger, 1994; Mendlinger and Pasternak, 1992a; Nukaya et al., 1980; Shannon and Francois, 1978). These differences may be due to differences in either cultural conditions or time of exposure to salinity.

Salinity improved fruit quality by increasing the concentrations of sugars, titratable acids, and TSS. This is in agreement with other investigations (Mendlinger, 1994; Mendlinger and Pasternak, 1992a; Shannon and Francois, 1978). Gillette (1985) indicated that NaCl enhanced the taste of food by improving the flavor balance. This could be due to the high concentrations of Na and Cl in the fruit, which agrees with our findings (data not shown). The increase in TSS may in part compensate for lower yields.

Marketable fruit yield was negatively correlated with leaf Na and Cl concentrations at the 16 May sampling date, thus high leaf Na and Cl may contribute to lower fruit yield. The fruit yield reduction does not seem to be exclusively associated with the high Na and/or Cl concentrations in the leaves, because for each salinity level similar Na and Cl concentrations were found, irrespective of when salinization began. Under saline conditions, fruit yields improved when salt treatment was applied later. This could indicate that the effect of salinity level is related to the time of exposure to salt. Yield reduction may also have been associated, in part, with a nutrient imbalance caused by disturbed uptake or distribution of essential mineral nutrients. Leaf N-NO_3 concentrations decreased with salinity level at each salinization time. Wilcox (1972) reported that melon fruit yield was higher when the concentrations of N_t and N-NO_3 in the petiole were 4.5% and 1.5%, respectively, during both the vegetative and fruit initiation stages.

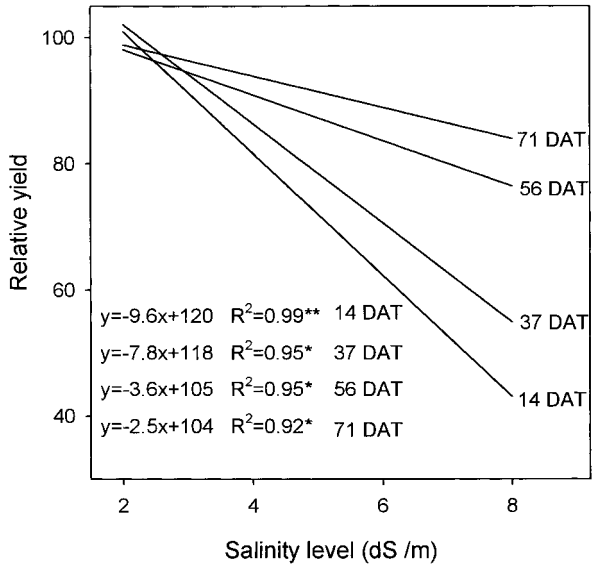

Fig. 1. Linear regression equations relating yield of 'Galia' melon to time (DAT) of irrigation with water differing in salinity level. *,**Significant at $P \leq 0.05$ or 0.01, respectively.

Table 3. Effect of water salinity level and time of application on fruit characteristics of 'Galia' melon.

Salinization time (DAT)	Salinity level (dS·m^{-1})	pH	EC (dS·m^{-1})	Acidity (g citric acid/ 100 mL)	TSS (°Brix)	Reducing sugars (g·L^{-1})	Thickness (mm) Peel	Thickness (mm) Pulp	Firmness (N)
14	2	6.6	6.8	0.08	7.6	63.1	5.7	28.5	45.7
	4	6.3	7.4	0.09	8.1	85.4	5.8	28.9	46.8
	6	6.3	7.7	0.10	9.9	78.5	5.5	27.7	46.6
	8	6.2	9.1	0.12	10.5	96.2	5.9	23.9	44.5
	Mean	6.3	8.1	0.10	9.50	86.7	5.7	26.8	46.0
37	4	6.4	7.4	0.08	8.6	67.8	5.4	28.4	49.8
	6	6.3	7.7	0.12	9.4	67.8	6.0	26.3	45.2
	8	6.2	9.3	0.10	9.2	110.6	5.8	23.7	46.2
	Mean	6.3	8.1	0.10	9.07	82.1	5.7	26.1	47.1
56	4	6.4	7.6	0.09	8.2	66.3	6.0	27.9	44.1
	6	6.5	9.1	0.09	10.1	83.4	5.8	28.3	44.9
	8	6.1	9.0	0.11	10.5	76.4	5.6	26.5	41.7
	Mean	6.3	8.6	0.10	9.60	75.4	5.8	27.6	43.6
71	4	6.5	7.4	0.08	8.9	75.4	6.0	30.0	45.3
	6	6.4	8.1	0.10	8.6	83.2	5.6	28.4	42.1
	8	6.0	8.8	0.12	8.6	81.7	5.6	25.9	41.3
	Mean	6.3	8.1	0.10	8.70	80.1	5.7	28.1	42.9
Mean	4	6.4	7.5	0.09	8.45	73.7	5.8	28.8	46.5
	6	6.4	8.2	0.10	9.50	78.2	5.7	27.7	44.7
	8	6.1	9.1	0.11	9.70	91.2	5.7	25.0	43.4
ANOVA									
Salinity level		30.3***	41.2***	3.1*	13.1***	6.2**	1.3NS	41.3***	5.6**
Salinization time		0.6NS	1.9NS	0.9NS	2.9*	2.1NS	0.5NS	4.9**	6.0**
Salinity × time		3.7**	2.9*	0.7NS	2.4NS	3.1*	5.6***	2.6*	1.6NS

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 4. Effects of water salinity level and time of application on leaf mineral composition (% dry weight) of 'Galia' melon at two sampling dates.

Salinization time (DAT)	Salinity level ($dS \cdot m^{-1}$)	Cl	Na	N_t	N-NO_3	P	K	Ca	Mg
				16 May (67 DAT)					
14	2	0.61	0.06	5.08	0.96	0.62	3.48	2.03	0.36
	4	0.84	0.10	5.13	0.82	0.65	3.43	2.45	0.31
	6	1.69	0.60	5.40	0.91	0.52	3.30	3.08	0.28
	8	1.56	0.38	5.45	0.74	0.56	3.21	3.28	0.30
		1.36	0.36	5.33	0.82	0.58	3.31	2.94	0.30
37	4	1.08	0.15	5.26	0.81	0.62	3.96	2.75	0.29
	6	1.46	0.29	5.24	0.74	0.55	3.56	3.83	0.32
	8	2.16	0.33	5.14	0.49	0.53	3.42	3.86	0.29
		1.57	0.26	5.21	0.68	0.57	3.65	3.48	0.30
56	4	0.76	0.10	5.39	0.83	0.65	3.56	2.24	0.33
	6	1.54	0.34	5.21	0.76	0.51	3.70	2.97	0.35
	8	1.76	0.33	5.15	0.60	0.54	3.39	2.57	0.37
		1.35	0.26	5.25	0.73	0.57	3.55	2.59	0.35
	Mean	0.89	0.12	5.26	0.82	0.64	3.65	2.48	0.31
		1.56	0.41	5.28	0.80	0.53	3.52	3.29	0.32
		1.83	0.35	5.25	0.61	0.54	3.34	3.24	0.32
ANOVA									
Salinity level		74.6^{***}	30.3^{***}	1.7^{NS}	19.3^{***}	19.5^{***}	6.8^{***}	9.9^{***}	8.0^{***}
Salinization time		3.3^{**}	2.4^{*}	0.4^{NS}	7.8^{**}	0.2^{NS}	9.6^{***}	7.8^{**}	13.7^{***}
Salinity × time		3.9^{**}	3.1^{*}	2.3^{*}	1.6^{NS}	0.9^{NS}	2.5*	0.8^{NS}	1.7^{NS}
				2 July (114 DAT)					
14	2	1.08	0.38	3.40	0.71	0.53	3.56	7.22	0.24
	4	2.00	0.61	3.16	0.51	0.49	2.42	7.88	0.25
	6	3.30	1.05	2.87	0.28	0.46	1.90	7.53	0.30
	8	4.19	1.46	3.07	0.40	0.46	1.70	5.95	0.21
		3.16	1.04	3.03	0.40	0.47	2.01	7.12	0.25
37	4	1.65	0.59	2.87	0.43	0.64	2.71	7.35	0.21
	6	3.96	1.45	3.17	0.35	0.52	1.91	6.51	0.23
	8	4.30	1.21	2.79	0.27	0.56	2.01	7.08	0.26
		3.30	1.08	2.94	0.35	0.57	2.21	6.98	0.23
56	4	1.63	0.63	2.94	0.54	0.48	2.76	6.34	0.24
	6	3.88	2.03	3.27	0.42	0.48	1.33	5.50	0.22
	8	4.91	1.51	3.39	0.27	0.70	2.10	4.96	0.33
		3.47	1.39	3.20	0.41	0.55	2.06	5.60	0.26
71	4	1.78	0.65	3.12	0.60	0.48	3.52	7.56	0.24
	6	2.26	0.74	3.05	0.48	0.61	3.44	7.44	0.25
	8	5.54	1.95	2.91	0.25	0.64	3.01	4.00	0.23
		3.19	1.11	3.03	0.44	0.58	3.32	6.33	0.24
Mean	4	1.77	0.62	3.02	0.52	0.52	2.85	7.28	0.24
	6	3.35	1.32	3.09	0.38	0.52	2.15	6.75	0.25
	8	4.74	1.53	3.04	0.30	0.59	2.21	5.50	0.26
ANOVA									
Salinity level		19.9^{***}	7.7^{**}	1.6^{NS}	8.2^{**}	0.6^{NS}	12.0^{***}	3.1^{*}	0.2^{NS}
Salinization time		0.2^{NS}	0.8^{NS}	1.5^{NS}	0.4^{NS}	3.0^{*}	8.6^{**}	2.5^{*}	0.3^{NS}
Salinity × time		1.9^{NS}	1.9^{NS}	1.4^{NS}	0.9^{NS}	1.4^{NS}	0.7^{NS}	1.6^{NS}	1.2^{NS}

$^{NS, *, **, ***}$Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

In the present study, the values of N_t on 16 May were similar, whereas those of N-NO_3 were lower.

Leaf K content at the 2 July sampling date was reduced by salinity level, only when salinization began 14 DAT. For melon plants, adequate K values vary from 2.9% in the leaf lamina to 8.6% in the petiole (Bhella and Wilcox, 1989). In our study, leaf tissue sampled on 2 July, from plants receiving 6 $dS \cdot m^{-1}$ applied at 14 DAT or 8 $dS \cdot m^{-1}$ applied at 37 DAT, could have been deficient in K.

In conclusion, the results of this experiment confirm that, with appropriate management, depending on the concentration of salts in the water and on the duration of exposure, brackish waters can be used for growing 'Galia' melons in perlite with minimum fruit yield losses and, at the same time, improved fruit quality. This production system may conserve good quality water for other uses. The detrimental effects of salinity may be related to the time during which high concentrations of Cl and Na remain in the leaves and to a disturbance of the N-NO_3 and K nutrition and metabolism in the plants.

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