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Yield and Fruit Quality of Drip-irrigated Cantaloupe under Salt Stress Conditions in an Arid Environment

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Abstract: Drip irrigation has the greatest advantages over other irrigation methods when saline water is used. In irrigated lands, the production of total and marketable yield depends largely on the quantity and salinity of the irrigation water. The performance of field-grown cantaloupe (*Cucumis melo- var. Cantaloupensis*) in 2-years was compared with fresh water applied at crop water requirement, 1.0ETc (as a control) or saline water (3.8 dS/m) applied at amounts equivalent to 1.0ETc, 1.2ETc and 1.4ETc, respectively. The occurrence of maximum soil water content and minimum salinity in the root zone during the growing seasons was noted only for 1.4ETc while irrigation regime at 1.0ETc was found unsuitable under saline conditions. Saline water significantly depressed cantaloupe total yield but the reduction was minimal under 1.4ETc irrigation regime. Salinity reduced average fruit weight while the number of fruit per plant remained almost stable regardless of the irrigation regime. Although the differences in fruit yield were significant, grading for export quality according to suitable fruit size and appearance almost compressed the differences in total yield between fresh and saline water plants. Total yield with saline water was almost 18-32% lower than with fresh water but offered several benefits as the absolute exportable yield was equaled to that of the control but the export rate was 90 versus 72%, respectively. However saline water provides an attractive compromise between fruit size and quality where 28% of the fresh water fruits were either too large, poorly netted or irregularly shaped, while plants irrigated with saline water had extremely high export rates. Moreover, saline water contributed markedly to the improvement of fruit quality by increasing total soluble solids and sugar contents. Considering the results of two years, the use of mild saline water for irrigation appears to be an attractive approach as a tool to optimize cantaloupe production with taking advantage of saline water effects on crop quality.

Key words: Drip irrigation, Saline water, Irrigation regime, Cantaloupe, Fruit quality

INTRODUCTION

The shortage availability of fresh water has become a worldwide problem, which supports the development of alternative, low quality water resources for agricultural use. Salinity is a significant factor in many of the irrigated lands and must be considered in developing optimum irrigation strategies. Salinity affects, both water and ion transport processes in plants which may change the nutritional status and the ion balance (Lauchli and Epstein, 1990) as well as many physiological processes (Munns, 2002) and thereby stunt the plant growth and reduce yields. However, moderate salinity level may be beneficial to crops by improving fruit quality (Petersen *et al.,* 1998; Auerswald *et al.,* 1999) and by reducing the excessive vegetative vigor of the vegetable crops usually observed during early growth in hydroponics (Savvas and Lenz, 2000). The time and amount of irrigation water application of various salinities along with crop selection based on salinity tolerance are some of the management variables. The effects of these management variables on crop yield and the amount and salinity of the water percolating below the root zone are necessary in establishing optimal management practices (Feng *et al.,* 2003).

Cantaloupe (*Cucumis melo* L.) has become one of the popular fruits that are often cultivated with irrigation in arid or semiarid regions such as in Egypt. It is cultivated in all the temperate regions of the world due to its good adaptation to soil and climate. Fruits are consumed in the summer period and are popular because the pulp of the fruit is very refreshing, high nutritional and sweet with a pleasant aroma. In agreement with the Maas and Hoffman (1977) classification, most reports defined melons as a moderately sensitive crop

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(salinity threshold of 1.0 dS/m and 8.4% yield decline/dS/m) (Shannon and Francois, 1978; Mangal *et al.,* 1988). Several reports indicated that salt stress brought about an increase in parameters of fruit quality, such as total soluble sugars (TSS) (Meiri *et al.,* 1995; Mendlinger, 1994), and fruit appearance (Mendlinger and Fossen, 1993). However, the salinity-induced increase in fruit quality has always been accompanied by a significant reduction in yields and the decrease in yield under saline conditions was a direct consequence of reduced fruit size, attributed to the effect of the osmotic component of soil water potential on the plant (Meiri *et al.,* 1995; Shani and Dudley, 2001). The use of deep sandy soils, which is aimed to alleviate soil salinity, may be risky in arid conditions, where high evaporative demands aggravate the low water availability that characterizes these types of soils. Frequent daily regimes of drip irrigation reduce the negative effect of salinity on fruit size, but that is not enough to provide the desired range of fruit size and the consequent increase in yield. Saline irrigation water strongly diminished vegetative growth and plant size in cantaloupe, as compared to fresh water plants.

Information on crop-water production functions for irrigation with saline waters is required for the improvement and development of optimum irrigation management strategies. The crop-water production function is unique for each crop, as crops vary in sensitivity to salinity (Letey *et al.,* 1985). A linear relationship between the marketable part of the crop and evapotranspiration has been reported for non-saline irrigation water when all the applied water was subject to evapotranspiration (Kipkorir *et al.,* 2002). Under irrigation with saline water, once the root zone salinity is sufficient to cause a yield loss, some part of the applied water drains down the root profile (Letey and Dinar, 1986). Current information on the leaching requirement could be improved to provide optimum irrigation scheduling, which is considered to be that amount of water that maximizes profit for the grower. Based on the above considerations, a two years field experiments was carried out to compare the performance of drip-irrigated cantaloupe using fresh or saline water under different irrigation regimes. This plant species is moderately salt-tolerant for which salinity is known to impact fruit size, quality and plant mineral composition.

MATERIALS AND METHODS

The experiment was conducted in 2006 - 2007 at Nubaria region, El-Behira province west of Nile Delta of Egypt during the late summer growing season (August - November) using drip irrigation system. This area is a desert region, and the soil of the experimental site was deep, well-drained sandy composing of 87.7% sand, 8.8% silt and 3.5% clay, with an alkaline pH 8.2, EC 2.87 dS/m, $CaCO_3$ 1.4%, O.M 0.25%. The available N, P and K were 16, 5 and 65 mg/kg soil, respectively before the initiation of the experiment. The average water content at field capacity from surface soil layer down to 60 cm depth at 20 cm intervals was 12% and the water holding capacity for the corresponding depths was 25% respectively. Cantaloupe plants (*Cucumis melo var. Cantaloupensis*) namely hybrid 'Galia' were cultivated in 2 m wide beds, pre-furrowed to receive salt free organic manure, at 50 m^3/ha, super phosphate at 250 kg/ha and potassium sulphate at 125 kg/ha prior to planting, as is customary in the region. Drip lines with 4 liter/h discharge rate at a spacing of 50 cm apart were put directly on surface of each soil bed. Single rows were planted parallel to the drip lines at adjacent to water sources. Sowing took place on August 15, three cantaloupe seeds were sown at about 5 cm from each dripper, and the final plant stand was thinned to 2 plants/dripper (20 000 plants/ha).

Irrigation treatments included application of water at input amounts equivalent to 100, 120 and 140% of actual crop water requirement (ETc). The (ETc) was estimated by multiplying reference evapotranspiration with crop coefficient ($ETc = ETo \times K_C$) for different months based on crop growth stages using the model suggested by Penman-Monteith's formula (Allen *et al.,* 1998). Amounts of irrigation water used after planting were 380, 460 and 540 mm during the growing season for 1.0ETc, 1.2ETc and 1.4ETc respectively. Irrigation frequency was running daily from local well water having EC 3.8 dS/m. The concentrations of the major ions expressed in mg/l were as follows: Na^+ 420, Ca^{2+} 256, Mg^{2+} 75, K^+ 98, Cl^- 958, SO_4^{2-} 393 and HCO_3^- 92. Fresh (canal water (0.45 dS/m) throughout the growing season served as control and was applied based on 1.0ETc. The experiment was arranged in randomized complete block design with three replications in 6 m wide × 10 m long plots. Nitrogen was applied on weekly basis at the rate of (200 kg N/ha) as NH_4NO_3 through drip fertigation in a split doses and commenced after two weeks of planting. This was done along with phosphorus (120 kg P/ha), as phosphoric acid (85%) and potassium (250 kg K/ha) as K_2SO_4 respectively. All NPK fertilizers were injected directly into the irrigation water using venture-type injector. To determine moisture and salt contents for each treatment, soil samples were taken from the wetted area just after the end of irrigation periodically at early, mid and late season at vertical intervals of 10 cm down to 30 cm, using tube auger. Soil moisture content was determined gravimetrically. All soil samples were air-dried and sieved through a 2 mm sieve to determine EC values based on soil paste extracts using a conductivity meter.

To follow vegetative growth, four plants per replication were sampled from each plot 30, and 60 days after emergence. The plants were divided into leaves and stems to determine fresh and dry weight. About 10 representative fresh leaves were measured for leaf area, after which they were dried for 48 h in an oven at 70 °C for calculation of specific leaf area (m^2 g/dw). The leaf area index (LAI) was calculated by multiplying specific leaf area by total leaf dry weight, then dividing by the ground area occupied by the four plants. Eighty days after planting, mature fruit were picked every 3 days, counted, weighed and sorted to three categories: exportable, local market and unmarketable fruits. Segments of three representative marketable fruits from each plot were peeled, and frozen for sweetness analysis. The pulp-samples were weighted and a corresponding 50% amount of distilled water was added before samples were processed using a blender, centrifuged (10 000 rpm). Sucrose, glucose, fructose and total soluble solids (TSS) in the supernatant were determined using a refract meter according to Lester, *et al.,* (2005). The dried material of plant samples of leaves and stems was ground for ion analysis (Na^+ and Cl^-). Sodium was measured by flam photometer using the method described by (Jackson, 1973) and Cl^- was determined by titration against $AgNO_3$ (Eaton *et al.,* 1995).

RESULTS AND DISCUSSIONS

Water and Salt Dynamics in the Root Zone:

The distribution of roots in the soil profile as indicated by visual assessment indicated that soil depth of 5-20 cm along the lateral is the most active root zone, which should be managed properly to minimize salinity hazards. The water content under 1.4ETc was much higher than under 1.0ETc and 1.2ETc for all soil depths (Table 1). The maximum water content for D_{10} and D_{20} was comparable for all irrigation regimes while at D_{30}, soil water content reached a maximum value under 1.4ETc irrigation regime, probably because of greater input of irrigation water. However, with increasing amounts of water applied, it seems that the wetted region exhibited a vertically elongation pattern and extended below 30 cm in the vertical direction beneath the dripper. A greater volume of water applied produced higher water content within the wetted volume, as also indicated by Li *et al.,* (2003).

Table 1: Moisture content and EC values in the root zone with fresh and saline water under different irrigation regimes at distance of D_{10} (0-10), D_{20} (10-20) and D_{30} (20-30 cm) soil depth under drippers during the season. (mean of two seasons).

Irrigation water	Applied water	Early season			Mid season			Late season		
		D_{10}	D_{20}	D_{30}	D_{10}	D_{20}	D_{30}	D_{10}	D_{20}	D_{30}
		Moisture content (%)								
Fresh	1.0ETc	22	18	10	23	20	13	24	20	14
Saline	1.0ETc	23	18	11	24	21	14	25	20	15
	1.2ETc	25	22	14	27	23	16	26	24	18
	1.4ETc	26	24	20	28	25	22	28	26	22
		Salt concentration (dS/m)								
Fresh	1.0ETc	0.9	0.5	0.7	1.2	0.7	0.9	1.6	0.9	1.5
Saline	1.0ETc	8.8	4.5	6.2	9.5	5.8	7.4	11.7	6.5	8.3
	1.2ETc	6.2	4.1	5.7	7.3	4.7	5.6	8.5	5.3	7.5
	1.4ETc	5.6	3.7	3.9	5.8	4.2	4.5	7.9	4.7	5.2

The EC values increased with increases in radial distance from the dripper and with the advance in crop growth for each irrigation regime. As expected the salt concentration under 1.4ETc was much lower than under 1.0ETc and 1.2ETc for all soil depths. Under 1.4ETc at D_{20}, the EC values varied very little, ranged from (3.7 to 4.7) dS/m during the growing season, and were very close to the salinity of the irrigation water. The EC values under 1.2ETc at the corresponding depth ranged from (4.1 to 5.3) dS/m and that under 1.0ETc from (4.5 to 6.5) dS/m. The EC values at D_{30} under 1.4ETc ranged from (3.9 to 5.2) dS/m, from (5.7 to 7.5) dS/m for 1.2ETc, and from (6.2 to 8.3) dS/m for 1.0ETc. Therefore, the roots at D_{20} and D_{30} under 1.4ETc were in a relatively less salt stressed conditions than either under 1.0ETc or 1.2ETc and the salinity stress in the root zone might had some adverse effects on root water uptake for both 1.0ETc and 1.2ETc irrigation regimes. It seems that under the 1.0ETc regime the salinity risk associated with decreases in water content, especially in the wet end range, was high compared to 1.4ETc. The previous relatively small difference in water content is important in sandy soil, because the maximum water content in this sand is low and there was a rapid increase in soil salinity with decreasing water content.

These results are in agreement with those of Meiri *et al.* (1995), who concluded that for a given saline irrigation water treatment, relative melon yield was increased by increasing leaching fraction, due to a reduction of the average root zone salinity. However, the first irrigation regime (1.0ETc) was found unsuitable for irrigation with saline water, because of the tendency of salts to increase in the root zone; the influence of water content on soil salinity was restricted to a small depth of about 0-20 cm from the dripper and beyond this range salt concentration was relatively higher. The EC values were highest under the 1.0ETc at D_{20} and D_{30} than under 1.2ETc or 1.4ETc, indicating that relatively small changes in water content could generate considerable changes in soil salinity. Salt concentration in the mid season was considerably higher than in early season for the lower irrigation regimes, which can be attributed to the accumulation of salts in the root zone. Irrigation with water with salinity that exceeds the threshold salinity level of the crop would be expected to have a major impact on soil salinity and crop yield. However, the EC values may reach to limiting level in the lower portion of the root zone, and hence, increasing amounts of applied water is imperative to overcome this limitation (Shalhevet, 1994). According to Letey and Dinar (1986), under conditions where limiting salinities exist near the lower boundary of the root zone, applying more of the same irrigation water will initially result in increased crop-water uptake with little impact on soil salinity and on the leaching fraction.

Fruit Yield and Plant Growth:

Fresh irrigation water applied throughout the growing season resulted in the highest cantaloupe total and marketable yield while under saline conditions the yield was significantly lower (Table 2). Cantaloupe has been reported as moderately salt tolerant crop, (Shannon and Francois, 1978) with a threshold value of 1.0 dS/m and an 8.4% yield loss for each unit increase in EC of the soil. Total and marketable yield with saline water varied markedly according to the amount of applied water during the season. However, fruit yield increased with the irrigation amount input; total and marketable yield production were almost higher with 1.4ETc (28.67 t/ha and 27.15) than with 1.2Etc (26.11 and 24.38 t/ha) or with 1.0ETc (23.62 t/ha and 22.72), respectively.

Table 2: Yield and yield components of cantaloupe with fresh and saline water under different irrigation regimes. (mean of two seasons).

Irrigation water	Applied water	Fruit yield t/ha			Fruits per plant	Mean fruit weight (g)	Soft fruits t/ha
		Total	Marketable	Exportable			
Fresh	1.0ETc	34.83	30.25	25.17	5.75	735	7.96
Saline	1.0ETc	23.62	22.72	20.78	4.50	550	1.95
	1.2ETc	26.11	24.38	23.45	5.25	621	2.11
	1.4ETc	28.67	27.15	25.85	5.75	658	2.84
LSD 0.05	2.78	2.16	1.97	0.60	85	NS	

Incalcaterra *et al.,* (1999) also reported a positive response of cantaloupe yield and quality to increasing volume of saline water and found that plants irrigated with 40 liters of saline water gave higher early and total yields, and fruits of better quality than those irrigated with lower volumes of good quality water. The average fruit size of fresh water plants was significantly larger than that of all other treatments, whereas that of plants grown with saline water was significantly smaller. The lower total yield observed with saline water in comparison with fresh water was mainly due to a reduction in the mean fruit weight per plant and not to the number of fruits per plant except under 1.0ETc irrigation regime where the both parameter were significantly lowered, probably due to aborting of flowers and/or fruits as suggested by Del Amor, *et al.,* (1999). Depending on cultural conditions, time of exposure to salinity and the salinity level the mean fruit weight (Franco *et al.,* 1993; Mendlinger, 1994) or both the mean fruit weight and the number of fruits (Del Amor *et al.,* 1999; Bustan, *et al.,* 2005) can be the first cause of yield reduction while for higher salinity levels the number of fruits was also decreased. No significant differences in average fruit size occurred among other treatments.

The major visible effect of saline irrigation water on cantaloupe plants is the decrease in canopy size, and particularly in vegetative growth and leaf area index LAI (Table 3). The decline in LAI designates a substantial drop in the productivity of melon plants grown under saline conditions. Plant size, as indicated by canopy dry weight and by leaf area index was significantly smaller due to the exposure to irrigation with saline water.

However, the vegetative growth declined remarkably in plants that were irrigated with saline water at 1.0ETc during the intensive stage of fruit growth between 30 and 60 DAP. The salinity effects were most evident for LAI, which practically enhanced with increasing amount of water in 1.4ETc irrigation regime; increase canopy size and LAI, and hence the potential productivity of the cantaloupe plant. During the same period, the vegetative growth of fresh water plants continued, reaching to maximum LAI value of 3.52 at 60 days after planting.

Table 3: Canopy dry weight and leaf area index (LAI) of cantaloupe with fresh and saline water under different irrigation regimes. (mean of two seasons).

Irrigation water	Applied water	Canopy dw (g/plant)		LAI	
		30 days	60 days	30 days	60 days
Fresh	1.0ETc	34.5	51.2	3.02	3.52
Saline	1.0ETc	25.2	34.9	2.12	2.28
	1.2ETc	28.0	38.4	2.31	2.43
	1.4ETc	30.6	42.5	2.38	2.52

Fruit Quality:

The distribution of fruit size corresponded with the irrigation regime and with the salinity level in the soil. Grading for export quality according to suitable fruit size and appearance almost depressed the differences in total yield between fresh and saline water plants; about 28% of the fresh water fruits were either too large, poorly netted or irregularly shaped, while plants irrigated with saline water had extremely high export rates (Fig. 1). The efficiency of saline water was extremely high, as the absolute exportable yield equaled to that of the control but the export rates were 90 versus 72%, respectively. Moreover, post-harvest quality analyses that followed an export simulation period of 15 days revealed that saline water irrigation significantly reduced the portion of soft and unmarketable fruits.

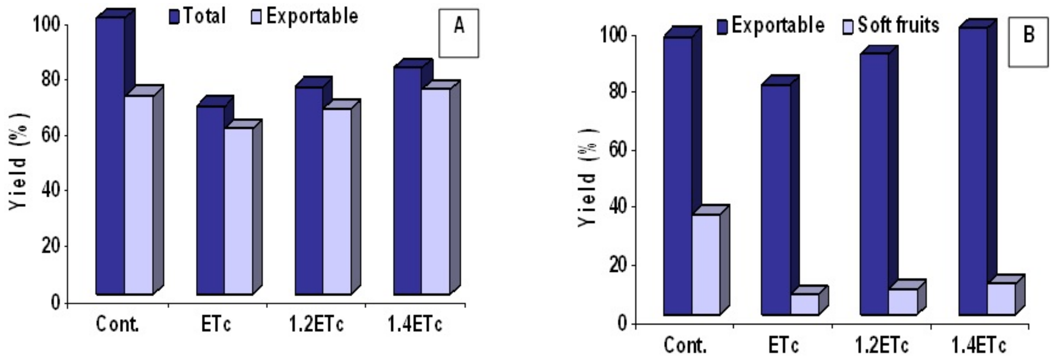

Fig. 1: Absolute export rates (% of total yield), (A) and soft fruits (% of exportable yield), (B) with fresh (cont.) and saline water under different irrigation regimes.

The expected influence pattern of saline water on fruit size was generally obtained, in spite of the differences in fruit yield were significant. The fruit size suitable for export seemed to favor saline water treatments, the milder the stress level, the larger the portion of desirable fruit size. When water with mild salinity level (3.8 dS/m) was applied during the growing season, the prevalence of the desirable fruit sizes was considerably high. The application of saline water produces the desired influence of salinity on fruit quality parameters. However, saline water brought about an attractive compromise between fruit size and fruit quality indicating that where manipulation with the salinity level of irrigation water is possible, the use of milder salinity level seemed favorable, as it brought about a desirable fruit size with better quality. The improvement of fruit quality in response to salt stress does not necessarily imply increased resistance to salt during fruit development.

Total soluble solids (TSS) were extremely higher, raged from 11.7 to 12.8 in fruit of plants received saline water versus 9.2 (mg/g of fresh weight) for plants received fresh water, respectively (Table 4). The contents of sucrose, glucose, fructose and total free sugars were influenced by saline irrigation water and were significantly higher by 27, 22, 18 and 24%, respectively, with saline than with fresh water. Botia, *et al.,* (2005) reported that fruit yield and quality parameters, such as firmness, total sugars and total soluble solids, improved markedly with saline water for the commercial production of Galia variety with appropriate agro management techniques. The taste and aroma of muskmelon depends on concentrations of sugars, total soluble solids (TSS), vitamins, aromatic substances, and amino acids in fruit, Lin *et al.,* (2004). Sucrose was the major form of sugar in ripe fruit, consistent with the result reported by Wang *et al.* (1996).

The trends of sugar accumulation in cantaloupe fruits showed significant difference between the fresh and saline treatments, with the highest in fruit of 1.0ETc treatment and lowest in 1.4ETc treatment. Zhao, *et al.,* (2001) reported that sucrose accumulation in ripe fruit was related to the activity of sucrose-metabolizing enzymes (acid invertase, neutral invertase, sucrose synthase, and sucrose phosphate synthase). Sucrose, glucose

Table 4: Total soluble solids TSS and sugar content in response to fresh and saline water under different irrigation regimes (mean of two seasons).

Irrigation water	Applied water	Sugar contents (mg/g of fresh weight)				TSS %
		Sucrose	Glucose	Fructose	Total	
Fresh	1.0ETc	36.5	12.7	15.3	64.5	9.2
Saline	1.0ETc	50.2	16.2	19.7	86.1	12.8
	1.2ETc	46.6	15.8	17.5	79.9	12.3
	1.4ETc	42.5	14.3	16.9	73.7	11.7

and fructose were the major sugars observed in juice of cantaloupe fruits and sucrose content showed the widest range among the treatments. Sucrose content, but not the content of glucose or fructose, was positively correlated with the increase in salt concentration, indicating that in the sweeter varieties sucrose is the most significant component that contributes to the variation in total sugars.

The improvement in fruit quality appears to be a consequence of simultaneous accumulation of ions and organic compounds in order to balance with the osmotic component of salt stress (Lauchli and Epstein, 1990). It appears that as root zone salinity levels increase, water uptake becomes the main problem of a melon plant, supporting Meiri *et al.* (1995), who suggested that the osmotic stress is the dominant component of salt stress in melon. Production and accumulation of sugars and other organic compounds in various compartments is an important strategy of plants to cope with osmotic challenges imposed by drought or salt stresses (Serrano, 1996) which may provide an explanation for the high TSS in fruits.

Mineral Composition:

Saline water treatments produced higher Na^+ and Cl^- concentration increases in all analyzed tissues, with regard to control plants (Fig. 2). Galia variety responded in different ways to Na^+ and Cl^- accumulation in their tissues. The stems accumulated high amounts of Na^+ and Cl^- than leaves, which significantly increased with time; Na^+ concentration in the leaves only varied slightly with time and little differences were found among treatments. Although Na^+ and Cl^- concentrations in leaves and stems increased with time, Cl^- increased more than sodium.

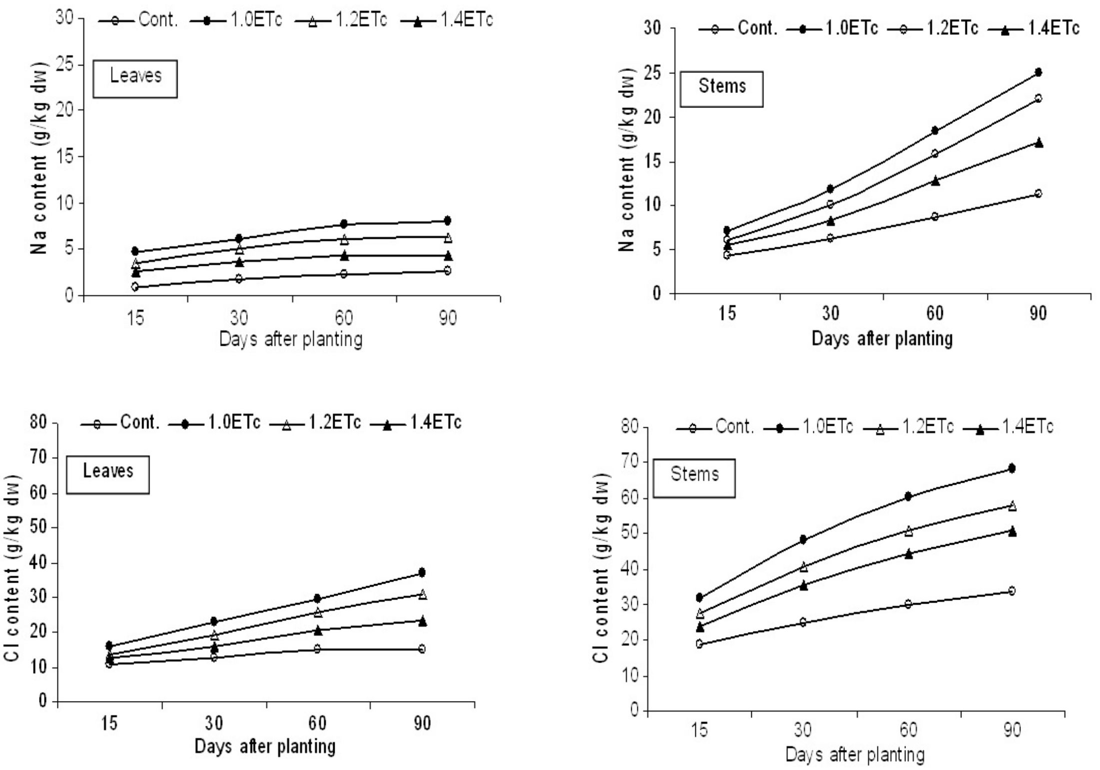

Fig. 2: Sodium and chloride concentrations (g/kg dw) in leaves and stems of cantaloupe, in response to fresh and saline water under different irrigation regimes during the growing season. (mean of two seasons).

The increase in uptake of both Na^+ and Cl^- in the stem tissues was more pronounced with the lowest water input, 1.0ETc and the reverse was true for the highest water input 1.4ETc. Similar results have been reported by Botai, *et al.,* (2005) how found that Cl^- increased more than Na^+ in the stems of Galia variety. The increase of leaf Na and Cl^- concentration in the analyzed tissues under 1.0ETc were probably due to the increase of soil salinity and thus, to a higher ion uptake. On the other hand, the soil salinity dilution under 1.4ETc would be the cause of maintaining the low leaves and stems Na^+ and Cl^- concentrations during the growing season. A proper control of the acquisition and distribution of Na^+ and Cl^- in plants is critical in the response of plants to salinity. In previous studies of Galia in hydroponic culture with high salinity, there was a significant correlation between shoot and root fresh weight and Na^+ concentration, and a certain degree of exclusion of Na^+ from the youngest leaves (Navarro *et al.,* 2000).

Finally, the hypothesis that proper management of saline water during the growth season was examined with the assumption that mild salinity level can increase plant size and consequently, fruit yield, but still preserve the known positive effects of salinity on fruit quality. According to the values and interactions between water content and soil salinity for a given soil depth, irrigation regime based on 1.0ETc is not suitable for irrigation with saline water. A yield reduction occurred during irrigation with saline water but the reduction was minimized under the 1.4ETc irrigation regime. The use of mild saline water significantly reduces yield but markedly improves fruit quality and other fruit components; exportable fruits were comparable to or even greater than the corresponding fruits resulted from fresh water.

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