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SALINITY STRESS

Effect of Salinity on Growth Parameters, Soil Water Potential and Ion Composition in *Cucumis melo* cv. Huanghemi in North-Western China

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Keywords
growth analysis; ion concentrations; saline irrigation; water consumption; water potential

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Abstract

A field trial conducted on the melon cultivar Huanghemi irrigated with saline water was carried out in Minqin County in the 2-year period, 2007 and 2008. In three irrigation treatments, different saline water concentrations were applied, that is 0.8 g l^{-1} (Control C), 2 g l^{-1} (Treatment S_1) and 5 g l^{-1} (Treatment S_2), reproducing the natural groundwater concentration in the county. The electrical conductivity of the saline water was as follows: 1.00, 2.66 and 7.03 dS m^{-1}, respectively. The aims of the study were (i) to monitor water consumption and water potential, (ii) assess, during the whole crop cycle, some growth parameters and their relations for estimating the morpho-functional plant response irrigated with saline water and (iii) determine the ion concentration in different plant tissues to evaluate which mechanism the plant activates in the presence of high salt concentrations.

Under salinity stress, the plants sustained the concentration of Ca, Mg and K, but at a level not sufficient to limit the Na adsorption. Therefore, the melon yield decreased and it was determined by a displacement of the ratio K/Na and by a lower $\bar{\psi}_t$ (total potential MPa). Consequently with increasing salinity, a significant reduction was observed in: water consumption (ETc, mm), leaf area duration (LAD, m^2 d), on shoot dry weight aboveground (W, g $plant^{-1}$), on specific leaf area (SLA, cm^2 g^{-1}) and on leaf area ratio (LAR, cm^2 g^{-1}). In treatment S_2, in addition to these changes which mainly affected the plant morphology with effects on the biomass produced, a moderate reduction was also observed in net assimilation rate (NAR, g m^{-2} d^{-1}), water use efficiency (WUE), a significant reduction in the energy conversion efficiency (ECE, %) and, in short, in a reduction in the relative growth rate (RGR, g g^{-1} d^{-1}).

Introduction

Melon is one of the most important and widely grown crops in the world. World melon production in 2006 was over 28 million t against 24 million t in 2004 (Castellini and Pisano 2006). The continent of Asia has the largest production, amounting to about 20.5 million t which accounts for 72 % of the world melon supply. Each country has its own specific melon cultivars and most of the crop is sold on local markets.

The *Cucumis melo* cultivar Huanghemi is widely cultivated in the Minqin Oasis in north-western China (Gansu province), one of the driest regions in the world (Shi and Zhang 1995). The combination of low and irregular rainfall, high summer temperatures and high evaporation during the summer (Ma et al. 2005)

combined with excessive groundwater extraction has resulted in serious consequences, such as groundwater salinization (Feng et al. 2005, Zhu et al. 2007). That said, use of saline groundwater is necessary to ensure the subsistence needs of local farmers. Groundwater salinity concentration varies in the oasis: in the southern part, salinity is around 0.8 g l^{-1}, in the middle part 2 g l^{-1} and in the north it is 5 g l^{-1}. Close to the desert at the far northern end of the oasis a salinity of around 10 g l^{-1} has been recorded.

Solutes in aqueous solution decrease osmotic potential, which affects plant water uptake (Steppuhn et al. 2005, Munns and Tester 2008). Osmotic effects contribute to reduce growth rate, change leaf colour, development and the duration of the leaf area (Tedeschi et al. 2011). Moreover, the excessive presence of specific ions and/or competition among specific cations or anions can cause ion toxicities or nutritional deficiencies (Shannon and Grieve 1999). Therefore, under salinity stress, plants trigger a variety of mechanisms that may occur concurrently both at a cellular and at the whole-plant level. Whether such mechanisms affect the morphological and/or functional level depends on many factors. The latter include the plant species or genotype, the salinity level, the composition of salts and nutrients in question and the environmental conditions.

Plant growth analysis is an explanatory, holistic and integrative approach to interpreting plant form and function. It uses simple primary data collecting through the growing season in the form of weights, areas, volumes and content of plant components to investigate processes involving the whole plant (Hunt et al. 2002). To date, few studies (Cramer et al. 1990, Saied et al. 2005, Tedeschi et al. 2011) have used growth analysis on the whole plant cycle to determine the effects of salinity on growth. Growth analysis has been used elsewhere (van den Boogaard et al. 1996, Hussain et al. 2000, Nautiyal et al. 2002, Hoffmann and Franco 2003, Anyia and Herzog 2004, Galmés et al. 2005, Ahmad et al. 2009) to evaluate the effect of water stress on crop production. These studies have been conducted on several species and are often restricted to a short growing season.

Given that the mechanisms activated by the plant can vary according to the cultivar, fertilizer applied and environmental conditions, growth analysis is a useful tool to elucidate and evaluate the plant's long-term response to the above factors. Against this background, our paper follows up a study in which the yield, crop tolerance and fruit quality of the *C. melo* cultivar Huanghemi was evaluated (Huang et al. 2012). Our previous study was limited to the assessment of the reduction in marketable yield and the increase of total soluble sugar with increasing salinity (Table 1) and did not cover the morphological or functional mechanisms that, the plant activates under salt stress.

Table 1 Summary of the effects of salinity on crop yield and fruit quality. Electrical conductivity of the irrigation water (ECw); total soluble sugar (TSS). Values followed by a different letter are significantly different at $P \leq 0.01$

Treatment	ECw (dS m^{-1})	Marketable fruit (t ha^{-1})	Fruit mean weight (g)	TSS (°Brix)	Flesh Hardness (kg cm^{-2})
C	1.00	37.8 a	1980 a	9.1 b	3.1
S_1	2.66	32.7 b	1728 ab	11.0 a	3.2
S_2	7.03	26.6 c	1507 b	11.6 a	3.3

Therefore, our aim was to evaluate and improve the knowledge of the effect of saline water irrigation on the Huanghemi melon cultivar grown in field trials in 2007 and 2008. The following specific objectives were established: (i) to monitor water consumption and water potential, (ii) assess, on the whole crop cycle, some growth parameters and their relations to ascertain the plant's morphological and functional response when irrigated with saline water and (iii) analyse the ion concentration in different plant tissues to document plant responses to high salt concentration.

Materials and Methods

Location, crop information and irrigation

The field experiment was carried out in 2007 and 2008 at the Gansu Desert Control Station located in the southern sector of the Minqin Oasis (Gansu province, latitude 38°35′N, longitude 103°03′E, altitude 1340 m). The soil properties were determined in the spring of 2007 following the methods described by Dane and Topp (2002) and Sparks (1996) for the 0.0–1.0 m soil layer: Texture: sand 36.9 %; silt 50.7 %; clay 12.4 %; organic matter 0.16 %; chemical properties: ECC 8.8, Ca 7.22, Mg 1.06, K 0.25, Na 0.51 (meq. per 100 g); pH 8.3; ECe 3.4 (dS m^{-1}); ESP 5.6 %.

During the crop cycle from May to August, the climatic conditions of the 2-year period (Fig. 1) diverged little from the previous 10-year average, with temperatures slightly lower (in July about −2 °C). Rainfall exceeded the 10-year average only in the month of July. However, during the crop cycle significant rainfall, reached only 21 mm (2-year average). Six small events during the 2007 for a total of 28.1 and 13.5 mm in two small events in 2008 occurred. In 2008 a rainfall event of 32.4 mm at 69 DAT made any further watering not necessary until commercial maturity (79 DAT).

Leaching irrigation with good quality river water (electrical conductivity, ECw 0.46 dS m^{-1}) was applied before sowing the Huanghemi melons, with 1500 and 1000 m^3 ha^{-1} in 2007 and 2008, respectively.

The irrigation was applied by furrows. In 2007 five irrigations with saline waters were applied on 23, 36, 49, 62 and 79 DAT with 510, 390, 390, 338 and 338 m^3 ha^{-1}, respectively, for all the treatments. In 2008 saline waterings were applied at 10, 23, 36, 49 and 62 DAT, with 427 m^3 ha^{-1} for all treatments, except for DAT 62 when 388 m^3 ha^{-1} were applied. In 2008 the rainfall of 32.4 mm at 69 DAT was added to the applied irrigation water.

A density of 2.67 plants m^{-2} was obtained by thinning the seedlings on 23/05/2007 and on 21/05/2008 (day zero after thinning, 0 DAT). The melon was sown in a double-row bed as shown in Fig. 2 the plants along a row were spaced 0.44 m apart. The furrows and part of the ridge were covered by black low-density polyethylene film (LDPE) 0.1 mm thick, the film covering about 75 % of the cultivated surface. Along the bottom of the furrows holes in the LDPE film were made 0.40 m apart to facilitate water infiltration and movement.

The field experimental design was a complete randomized block with three saline treatments and three replications, that is nine plots. Each plot was 13 × 9 m and it was surrounded by a cultivated strip 2 m wide to avoid interference between the plots. A central sector of 77 m^2 was used to measure the yield and the growth of plants during the growing season. The experimental set-up was the same in 2007 and 2008 and the saline treatments were repeated each year on the same plots. The saline treatments were obtained using water with different concentrations, with their composition (Table 2) reproducing the groundwater salinity in the region.

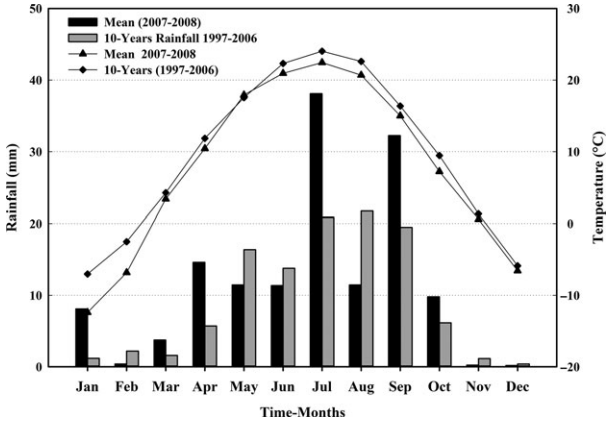

Fig. 1 Weather conditions, mean 2007–2008 and 10-year period in the Minqin area. Temperature (°C) (▲ 2007–2008 and ♦ 10 years 1997–2006). Rainfall (mm) by bars 2007–2008 ■ and the 10-year period 1997–2006 ■.

Table 2 Composition of irrigation water applied in the field trial. Groundwater present in the Minqin Oasis with the following concentrations: 0.8, 2 and 5 g l^{-1} ($Gw_{0.8}$, Gw_2 and Gw_5)

		Water		
Elements	Unit	$Gw_{0.8}$	Gw_2	Gw_5
Ca^{2+}	mg l^{-1}	87	126	280
Mg^{2+}	"	44	192	190
Na^+	"	52	229[1]	1000[1]
K^+	"	5		
CO_3^{2-}	"	0	14	0
HCO_3^-	"	296	307	360
Cl^-	"	120	323	890
SO_4^{2-}	"	225	739	1640
TDS	g l^{-1}	0.8	2.0	5.0
RSC	mmol l^{-1}	0.8	n.r.	n.r.
SAR	$mmol^{1/2}$ $l^{-1/2}$	1.6	4.2	15.9
SAR_{adj}	$mmol^{1/2}$ $l^{-1/2}$	1.20	6.54	36.62
pH		8.0	8.0	7.5
Treatment under study		C	S_1	S_2
EC_W of the treatment under study	dS m^{-1}	1.00	2.66	7.03

Total dissolved solids (TDS), residual sodium carbonate (RSC), sodium adsorption ratio (SAR), adjusted sodium adsorption ratio (SAR_{adj}) and the electrical conductivity of the irrigation water (ECw).
1The sum of Na and K together. n.r. (value not reported).

Soil and crop measurements

Measurements of soil moisture by the gravimetric method at 0 and 10 DAT, commercial maturity (79 DAT) and before and after each irrigation were carried out on two soil samples taken from each replication at depths of 0.0–0.3, 0.3–0.6 and 0.6–1.0 m in both years. The two soil samples were taken: one in the middle between two plants along the row. The other measurement was taken at 25 cm from the plant towards the centre of the twin row. The mean of these two measurements was used to compute the water balance of the three treatments as illustrated below. These measurements allow the crop cycle to be divided into the following intervals: 0–10; 10–23; 23–36; 36–49; 49–62 and 62–79 DAT.

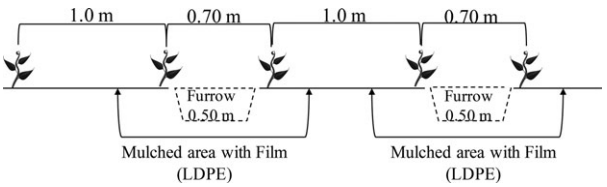

Fig. 2 Plant bed structure, furrow size and layout of the mulching in the trial plots with low-density polyethylene (LDPE) film.

On the soil samples taken at 0, 10 and 79 DAT and after each irrigation event and at the same depth reported for the soil moisture the electrical conductivity of the saturated paste (ECe) was determined according to Rhoades (1996).

The soil moisture and ECe measurements allowed the following to be calculated:

(a) $\overline{EC_e}$ = weighted average of the salinity in saturated paste (dS m^{-1}) of three soil layers of the profile 0.0–1.0 m for each time interval of the crop cycle, with weight taken equal to the thickness of each layer.

(b) EC_e^d = seasonal average of $\overline{EC_e}$

(c) $EC_s = \frac{\theta_s}{\theta} \times EC_e$ where

EC_s = electrical conductivity (dS m^{-1}) of the soil solution of the layer and date considered;

θ_s = saturated soil moisture (cm^3 cm^{-3}) of the layer considered;

θ = soil moisture (cm^3 cm^{-3}) of the layer and on the date considered.

(d) $\overline{EC_s}$ = weighted average of the soil salinity (dS m^{-1}) of three soil layers of the profile 0.0–1.0 m for each time interval of the crop cycle, with weight taken equal to the thickness of each layer;

(e) EC_s^d = Seasonal average of EC_s

(f) $\overline{\psi_\omega^{sw}} = \overline{EC_{sw}} \times 0.036$ where

$\overline{\psi_\omega^{sw}}$ is the osmotic potential of the extracted water of the soil profile 0.0–1.0 m (MPa) for each time interval of the crop cycle;

(g) $\overline{EC_{sw}}$ = weighted average of the soil salinity (dS m^{-1}) of three soil layers of the profile 0.0–1.0 m for each time interval of the crop cycle, with weight taken equal to the thickness of each layer and to the crop water uptake in each layer.

(h) EC_{sw}^d = seasonale average of $\overline{EC_{sw}}$ for the layer 0.0–1.0 m

(i) $\overline{\psi_m}$ = matric potential of the soil solution of the soil profile 0.0–1.0 m (MPa) for each time interval of the crop cycle, obtained by the average ψ_m of the three layers measured at the beginning and end of each time interval.

The laboratory-measured soil water retention curves, valid in the potential range between −0.01 and −1.5 MPa and for the three separate layers, were used to calculate the matric potential, as parameters *a* and *b* of the corresponding linear regressions reported below differed significantly.

ψ_m (0.0–0.3 m) = 1.929–0.151 × θ R^2 = 0.99***

ψ_m (0.3–0.6 m) = 2.712–0.140 × θ R^2 = 0.99***

ψ_m (0.6–1.0 m) = 2.922–0.169 × θ R^2 = 0.99***

ψ_m = $\log_{10}$ of the matric potential (MPa) of the layers and date considered;

θ = soil moisture (cm^3 cm^{-3}) of the layers and date considered.

Three plants per plot and replicate were harvested in 2007 and 2008 on 10, 23, 36, 49, 62 and 79 DAT, and at each date, the following parameters were determined: leaf area (LA; cm^2 and/or m^2), dry weight above ground (W; g $plant^{-1}$) and leaf dry weight (LW; g $plant^{-1}$). The averages of the three plants were used for statistical analysis and to calculate, for each time interval of the crop cycle and in accordance with Hunt (1982), the following:

- Leaf area duration LAD (m^2 d) = $(LA_i + LA_{i+1})/2 \times (T_{i+1} - T_i)$;
- Unit leaf area (ULR; g m^{-2} d^{-1}) or net assimilation rate NAR (g m^{-2} d^{-1}) = $(\ln LA_{i+1} - \ln LA_i) \times (W_{i+1} - W_i)/(LA_{i+1} - LA_i) \times (T_{i+1} - T_i)$;
- Specific leaf area SLA (cm^2 g^{-1}) = $(LA_{i+1} - LA_i) \times (\ln LW_{i+1} - \ln LW_i)/(\ln LA_{i+1} - \ln LA_i) \times (LW_{i+1} - LW_i)$;
- Leaf area ratio LAR (cm^2 g^{-1}) = $(LA_{i+1} - LA_i) \times (\ln W_{i+1} - \ln W_i)/(\ln LA_{i+1} - \ln LA_i) \times (W_{i+1} - W_i)$;
- Leaf Weight Ratio LWR (g g^{-1}) = $(LW_{i+1} - LW_i) \times (\ln W_{i+1} - \ln W_i)/(\ln LW_{i+1} - \ln LW_i) \times (W_{i+1} - W_i)$;
- Relative growth rate RGR (g g^{-1} d^{-1}) = $(\ln W_{i+1} - \ln W_i)/(T_{i+1} - T_i)$. where LA_i; W_i etc are the leaf area or the dry weight above ground at Time *i* (T_i) and the LA_{i+1} or W_{i+1}- are the leaf area or the dry weight above ground at Time *i*+1 (T_{i+1}) where i = 10; 23; 36; 49; 62 DAT and $i + 1$ = 23; 36; 49; 62; and 79 DAT.

Moreover, according to Gibbon et al. (1970) we estimated the energy conversion efficiency, ECE (%) = (Energy content of plant dry matter/Total solar energy available) × 100.

Determination of ion content in plant tissue

Parts of both apical and basal leaves and stems and portions of roots of the plants were harvested for growth analysis at 23, 49 and 79 DAT and were used for chemical analyses. To determine the ion content of Na^+, K^+, Mg^{2+} and Ca^{2+} in the plant tissue, 0.5 g of powdered sample was digested with a solution of HNO_3 and $HClO_4$ 10 : 1 (v/v), (Pandey and Sharma 2002), and subsequently filtered and centrifuged. The content of calcium, sodium, potassium and magnesium was determined by atomic absorption spectrometry (Varian Spectra AA 200, Victoria, Australia). To determine the Cl^- in the plant tissue, Lanthanum chloride 0.5 % (w/v) was added to 0.5 g of powdered sample, as reported by Kawashima and Valente Soares (2003). Chloride (Cl^-) was extracted with 15 ml of ultrapure water (Xu et al. 2006). The chloride content of the filtered mixture was determined by silver nitrate titration using $AgNO_3$ 0.1 N and an indicator agent containing 5 % K_2CrO_4 (w/v). Results of all ions were expressed as percentages of dry weight (% d.w.).

Statistical analysis

Statistical analysis was performed for each date by arranging the observations for 2 years in accordance with the virtual split-plot design (Gomez and Gomez 1984), where saline treatments were the main plot and the year the subplot. For all the parameters analysed, the variance of the error of the 2 years was homogeneous and the saline treatment × year interaction was absent. This allowed us to report and discuss the mean 2-year values. Mean values were compared using Duncan's multiple range test.

Results

Soil salinity, water consumption, root water uptake and water potential

The level of soil salinity to which the plants were exposed during the crop cycle (Fig. 3) was monitored by $\overline{EC_s}$, estimated as reported in Section Soil and crop measurements. $\overline{EC_s}$ is higher than $\overline{EC_e}$ since in an open field, with normal irrigation management, the soil moisture fluctuates between a maximum after irrigation and a minimum before the next irrigation but never reaches saturation, except for a very short time. For this $\overline{EC_s} > \overline{EC_e}$ and the differences are always highly significant ($P \leq 0.01$) at all dates and for all treatments, even if this could not be reported in Fig. 3. As shown in Fig. 3, the $\overline{EC_s}$ of the S_2 treatments, at all dates, was significantly higher than the control C while the $\overline{EC_s}$ of S_1, did not significantly differ from the control. Moreover, the regression of treatment S_2 ($\overline{EC_s} = 4.90 + 0.032 \times DAT$ with observations n = 18, that is 6 DAT × 3 replicates) shows a highly significant increase of $\overline{EC_s}$ over time ($R^2 = 0.81$***) unlike that of C ($R^2 = 0.061$ ns) and S_1 ($R^2 = 0.35$**).

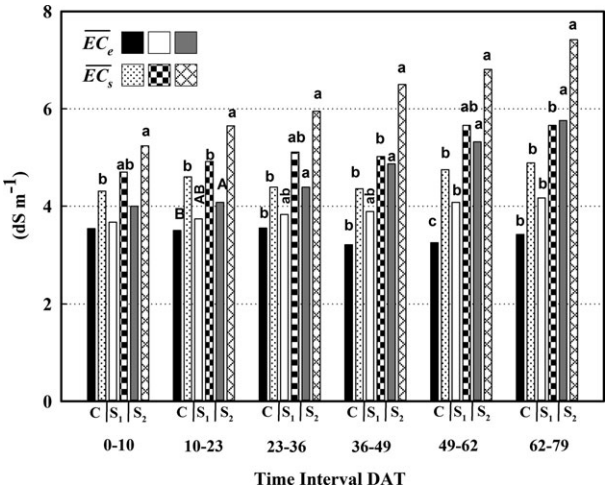

Fig. 3 Electrical conductivity of the soil profile 0.0–1.0 m for each time interval (DAT, days after thinning) of the crop cycle considered and for each saline treatments under study (C = ECw 1.0 dS m^{-1}; S_1 = ECw 2.66 dS m^{-1} and S_2 = ECw 7.03 dS m^{-1}). In particular in the plot the $\overline{EC_e}$ is the weighted average of the salinity in saturated paste (dS m^{-1}) of three soil layers for each time interval of the crop cycle, with weights taken equal to the thickness of each layer. The ■; □ and ▩ are the $\overline{EC_e}$ of the treatment C; S_1 and S_2, respectively. Inside each time interval, the values indicated by bars are significantly different at $P \leq 0.05$ if labelled with different upper case letters, at $P \leq 0.01$ if labelled with different lower case letters, not significantly otherwise. In the plot the $\overline{EC_s}$ is the weighted average of the electrical conductivity of the soil salinity of three soil layers for each time interval of the crop cycle, with weights taken equal to the thickness of each layer. The ⁝; ▩ and ▨ are the $\overline{EC_s}$ of the treatment C; S_1 and S_2, respectively. Inside each time interval, the values indicated by bars are significantly different at $P \leq 0.01$ if labelled with different letters.

Crop water use ETc was estimated by calculating the soil water balance for the entire soil profile 0.0–1.0 m and the entire growth cycle, that is from DAT = 0 till DAT = 79, and reported in Table 3. The water balance has been calculated as:

$$ET_c = (I + R)_{ir} + R + \Delta M_{0.79}$$

where: ETc = total crop water use; $(I + R)_{ir}$ = total irrigation and rainfall retained in the soil profile at each irrigation; R = total Rainfall in – between all irrigations and $\Delta M_{0.79}$ = difference between total soil water (0.0–1.0 m) at harvest and at planting date.

The $(I + R)_{ir}$ term has been obtained by adding up measured increases in total soil water (0.0–1.0 m) at each irrigation, obtained from measurements of soil water content in each soil layer as:

$$(I + R)_{ir,i} = \Delta M_i = M_{i+1} - M_i$$

where: ΔM_i = difference between total soil water content (0.0–1.0 m) at M_{i+1} after each irrigation, that is at $t = i + 1$ and M_i before the same irrigation, that is at $t = i$.

Changes in soil water content $\Delta M_{0.79}$ are shown (Table 3) with a positive sign when a decrease in soil

Table 3 Mean soil water balance for 2 years from 0 DAT (days after thinning) till 79 DAT, for each treatment (C = water at 0.8 g l^{-1}, ECw 1.0 dS m^{-1}, S_1 = water at 2 g l^{-1}, ECw 2.66 dS m^{-1} and S_2 = water at 5 g l^{-1}, ECw 7.03 dS m^{-1}) calculated at depth 0.0–1.0 m. ETc is crop evapotranspiration. The change in soil water content ($\Delta M_{0.79}$) is calculated as profile water content at 79 DAT minus profile water content at 0 DAT; R is the rainfall and $(I + R)_{ir,i}$ is the total retained water at irrigation

Treatments	Soil depth (mm)	$(I + R)_{ir,i}$ (mm)	R (mm)	$\Delta M_{0.79}$ (mm)	ETc (mm)
C	0.0–1.0	152.3	20.8	37.4	210.5
S_1	0.0–1.0	148.2	20.8	16.4	185.4
S_2	0.0–1.0	145.7	20.8	−6.5	160.0

moisture occurs, and with a negative sign when an increase in soil moisture is recorded.

ETc of all the treatments decreased with increasing salinity. An estimate of the decrease of ETc with increasing salinity is given by the trend of the cumulative ETc over time (Fig. 4). Starting on DAT = 49 the ETc rate becomes clearly different across treatments, being lower for treatment S_2.

Water extraction from the different soil layers depends first of all on root growth. Although melon roots may reach a depth of 2.0 m and extend the same distance laterally, they are more active in the first 30–40 cm of depth (Bianco and Pampini 1990). In this experiment until 10 DAT and in all treatments, water uptake comes 100 % from the surface layer (0.0–0.3 m). In the next time interval (10–23 DAT) in all treatments about 80 % of water uptake comes from the surface layer and 20 % from the layer 0.3–0.6 m. The contribution of the layer 0.6–1.0 m, amounting to about 10 % of the total with no difference between treatments, was recorded at time interval 23–36 DAT. This trend is in agreement with the progressive growth and deepening of the root system which can be assumed as roughly concluded by 36 DAT.

The osmotic potential $\overline{\psi_\omega^{sw}}$ (Fig. 5a), matric potential $\overline{\psi_m}$ (Fig. 5b) and the total potential ($\overline{\psi_t} = \overline{\psi_\omega^{sw}} + \overline{\psi_m}$) (Fig. 5c) during the crop cycle were calculated as described in Section Soil and crop measurements. $\overline{\psi_\omega^{sw}}$ of treatment C, an average −0.17 MPa, was slightly lower than the osmotic potential (−0.12 MPa) at soil saturation measured at the beginning of the experiment in 2007. $\overline{\psi_\omega^{sw}}$ of treatment S_2 from 23 DAT is always significantly lower than that of treatment C which does not always significantly differ from treatment S_1. By contrast, the $\overline{\psi_m}$ of treatment S_2 during the second part of the crop cycle is significantly higher than that of treatment C. This higher matric potential of S_2 is due to the lower water consumption. Except for the time interval 49–62 DAT, that is the period the maximum plant water requirement, $\overline{\psi_t}$ of the treatment S_2 was always significantly lower than the treatment C when $\overline{\psi_\omega^{sw}} > \overline{\psi_m}$.

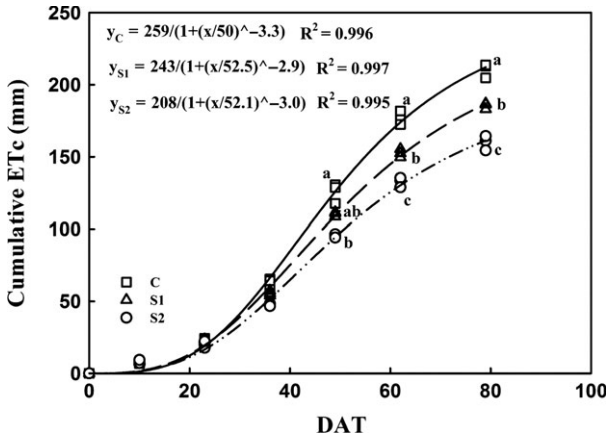

Fig. 4 Cumulative crop evapotranspiration against different time (DAT, days after thinning). Values indicated by data markers are significantly different at $P \leq 0.01$ if labelled with different lower case letters, not significantly otherwise.

Over the entire crop growth the mean values of $\overline{\psi_m}$, that is −0.087; −0.07 and −0.06 MPa for C; S_1 and S_2, respectively, were much higher than the corresponding values of $\overline{\psi_t}$, that is −0.26; −0.27 and −0.31 MPa. This shows that the osmotic potential was the dominant contribution to $\overline{\psi_t}$ also in the control C (2/3 $\overline{\psi_\omega^{sw}}$ and 1/3 $\overline{\psi_m}$). On the other hand, the drop in $\overline{\psi_m}$ (Fig. 5b) around DAT 49 shows that the irrigations were not sufficient to meet crop water requirement of the C and S_1 treatments, leading to uptake of soil water (Table 3). Accordingly, we have focused our evaluation of the effect of $\overline{\psi_m}$ on the period from DAT = 49 to DAT = 62 by determining the correlation of ETc and *W* with $\overline{\psi_m}$ $\overline{\psi_\omega^{sw}}$, and $\overline{\psi_t}$ for each treatment. Table 4, shows that even in the period of low matric potential these parameters were strongly influenced by $\overline{\psi_\omega^{sw}}$ and $\overline{\psi_t}$ but not by $\overline{\psi_m}$.

The mean seasonal values given above show that $\overline{\psi_m}$ was negligible in comparison with $\overline{\psi_\omega^{sw}}$ for the treatments S_1 and S_2. Even for the treatment C, $\overline{\psi_m}$ was relatively close to 0 and accounted for 30 % only of $\overline{\psi_t}$. The correlation analysis shown above indicates that no significant effect of the DAT 49–62 drop in $\overline{\psi_m}$ on growth indicators was observed.

Leaf area, biomass production and water use efficiency

Leaf area growth which peaked at 49 DAT for all treatments was followed by a reduction in leaf area, concurrently with the reproductive stage, due to plant ageing prior to plant death. The leaf area from 36 DAT significantly decreased as the salinity of the irrigation water increased. This effect is clearer with reference to cumulative LAD (leaf area duration; m^2 d) which takes into account the size and its duration: cumulative LAD increased over time (Fig. 6) at a diminishing rate with increasing salinity. The slopes of the regression curves are all highly significant for $P \leq 0.01$ and are 0.63, 0.53 and 0.42 DAT for C, S_1 and S_2, respectively. The smaller slopes of S_1 and S_2 compared to C explain the significant reduction of cumulative LAD from the time 36 DAT in S_2 and from 49 DAT in S_1 (Fig. 6).

Also dry matter accumulation above ground in grams per m^2 (*W*) occurred at a diminishing rate with the increase in salinity as shown (Fig. 7). A significant reduction in the accumulation of *W* with respect to the control C is shown in S_2 from 36 DAT and S_1 from 49 DAT onwards The progression of *W* over time (Fig. 7) is very similar to that of ETc (Fig. 4) and LAD (Fig. 6) for which significant differences are observed between treatments

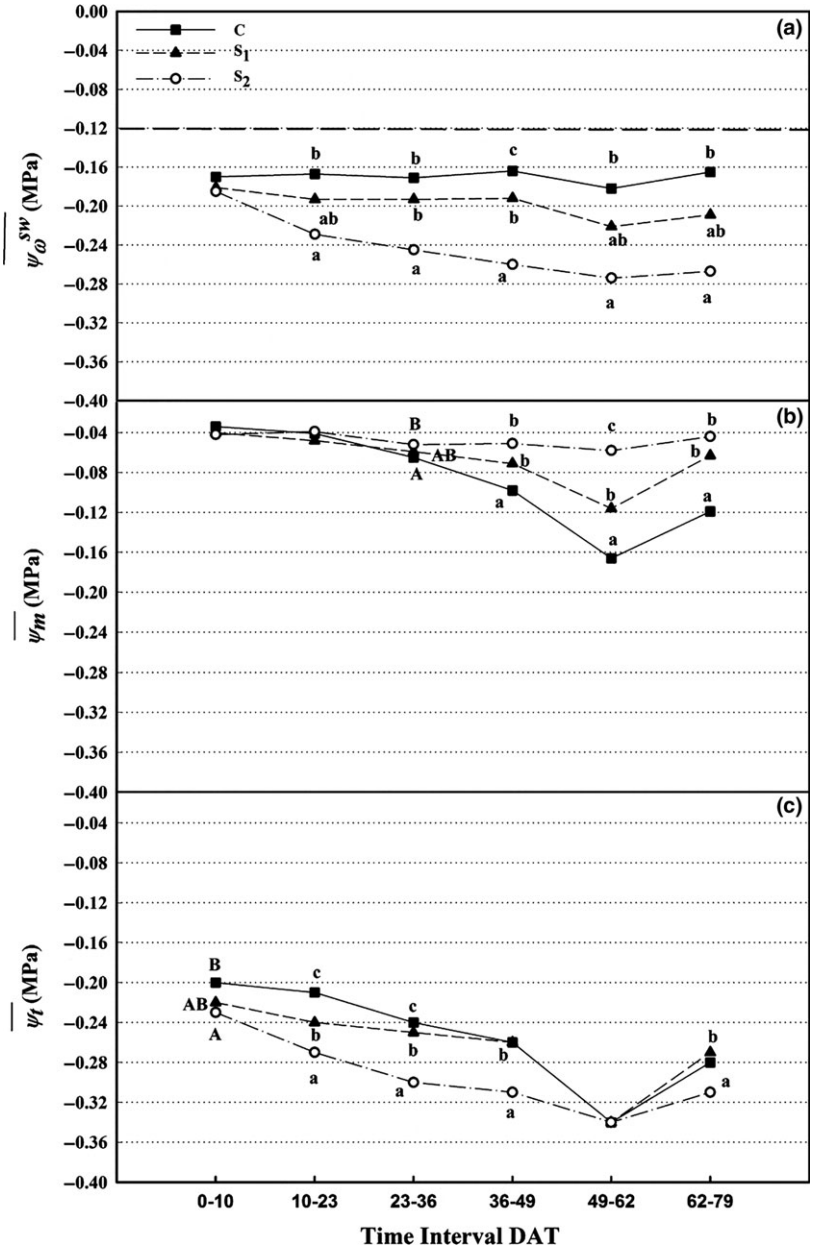

Fig. 5 Osmotic potential $\overline{\psi_{\omega}^{sw}}$ of the water extracted from the soil profile 0.0–1.0 m, the dotted line at (−0.12 MPa) is the osmotic potential at soil saturation (Fig. 5a), matric potential $\overline{\psi_m}$ of the soil solution of the soil profile 0.0–1.0 m (Fig. 5b) and total potential $\overline{\psi_t}$ of the soil solution of the soil profile 0.0–1.0 m (Fig. 5c) against each time interval (DAT, days after thinning) of the crop cycle for the different saline treatments (C = ECw 1.0 dS m^{-1}, S_1 = ECw 2.66 dS m^{-1} and S_2 = ECw 7.03 dS m^{-1}). Values followed by the same upper case letters within each time interval are not significantly different for $P \leq 0.05$ and are not significantly different at $P \leq 0.01$ if labelled with lower case letters.

Table 4 Correlation coefficient (R^2) for the time interval 49–62 DAT (days after thinning) of crop evapotranspiration ETc (mm) and the shoot dry weight W (g m^{-2}) with the osmotic potential $\overline{\psi_{\omega}^{sw}}$, the matric potential $\overline{\psi_m}$ and the total potential $\overline{\psi_t}$ in MPa for each saline treatment (C = water at 0.8 g l^{-1}, ECw 1.0 dS m^{-1}, S_1 = water at 2 g l^{-1}, ECw 2.66 dS m^{-1} and S_2 = water at 5 g l^{-1}, ECw 7.03 dS m^{-1})

	ETc (mm)			W (g m^{-2})		
Treatment	$\overline{\psi_{\omega}^{sw}}$	$\overline{\psi_m}$ (ns)	$\overline{\psi_t}$	$\overline{\psi_{\omega}^{sw}}$	$\overline{\psi_m}$ (ns)	$\overline{\psi_t}$
C	0.8908**	0.0323	0.9182**	0.9722**	0.1077	0.9072**
S_1	0.972**	0.1099	0.9084**	0.9711**	0.1212	0.8936**
S_2	0.9643**	0.0116	0.7801*	0.9854**	0.0079	0.8116*

**$P \leq 0.01$ and *$P \leq 0.05$

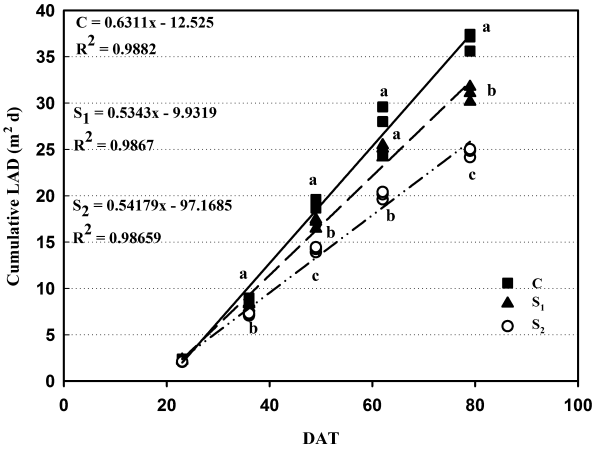

Fig. 6 Regression of the cumulative leaf area duration (LAD) against time DAT (days after thinning) and for the salinity treatment under study (C = ECw 1.0 dS m^{-1}, S_1 = ECw 2.66 dS m^{-1} and S_2 = ECw 7.03 dS m^{-1}). At each date values followed by the same letters are not significantly different at $P \leq 0.01$.

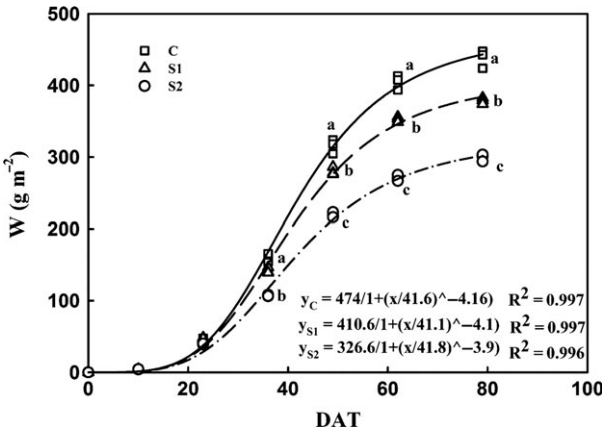

Fig. 7 Cumulative shoot dry weight; W against time DAT (days after thinning) and for salinity treatment under study (C = ECw 1.0 dS m^{-1}, S_1 = ECw 2.66 dS m^{-1} and S_2 = ECw 7.03 dS m^{-1}). At each date values followed by the same letters are not significantly different at $P \leq 0.01$.

comparable to those of *W*. This indicates a high degree of association of LAD with ETc and *W* and also of ETc with *W* for all treatments as confirmed by the following correlation coefficients which are all highly significant for $P \leq 0.001$.

ETc over LAD r = 0.996 for C, 0.998 for S_1 and 0.951 for S_2

W over LAD r = 0.983 for C, 0.984 for S_1 and 0.985 for S_2

W over ETc r = 0.989 for C, 0.987 for S_1 and 0.983 for S_2

Particular attention should be paid to the regression of *W* against ETc because the slope of this regression (2.18, 2.19 and 2.00 for C, S_1 and S_2, respectively) represents the average seasonal water use efficiency, WUE, in grams of *W* per kg of water consumed. The slope of S_2, significantly different from the other treatments ($P \leq 0.05$), it indicates a lower seasonal average of WUE of S_2 due to the lower values observed during the crop cycle (Fig. 8). Indeed, the analysis of variance of WUE at different DAT (Fig. 8) shows that from 36 DAT and up to the end of the crop cycle the WUE of the treatment S_2 was significantly lower at $P \leq 0.01$ than in the other treatments.

Growth analysis

During the crop cycle, the relative growth rate (RGR) of the S_2 treatment was significantly different from treatments C and S_1, consequently also the seasonal average of S_2 was significantly different from C and S_1 (Table 5). The RGR response to salinity can be explained by the indexes LAR, NAR, LWR and SLA which all contribute, directly or indirectly, to the formation of RGR. Indeed, RGR = LAR × NAR and LAR = LWR × SLA.

In this experiment LWR increased with rising salinity and the seasonal average of S_2 was significantly different from treatment C and S_1 (Table 5). Hence, with increasing salinity there was a growth in the proportion of dry matter accumulating in the leaves.

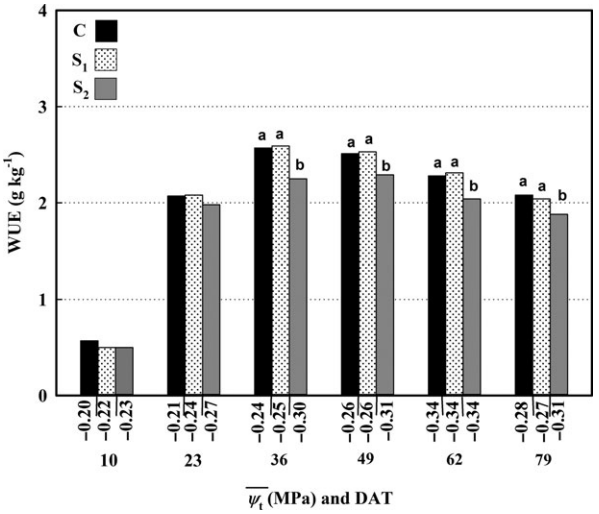

Fig. 8 Effect of salinity on the water use efficiency (WUE) at different days after thinning (DAT) and at different total water potential $\overline{\psi_t}$ for each treatment and DAT. For salinity treatment under study (C = ECw 1.0 dS m^{-1}, S_1 = ECw 2.66 dS m^{-1} and S_2 = ECw 7.03 dS m^{-1}). At each DAT the values indicated by bars are significantly different at $P \leq 0.01$ if labelled with different letters.

Table 5 Seasonal average of the relative growth rate (RGR), leaf weight ratio (LWR), specific leaf area (SLA), leaf area ratio (LAR) and net assimilation rate (NAR) for each saline treatment under study (C = water at 0.8 g l^{-1}, ECw 1.0 dS m^{-1}, S_1 = water at 2 g l^{-1}, ECw 2.66 dS m^{-1} and S_2 = water at 5 g l^{-1}, ECw 7.03 dS m^{-1})

Treatment	RGR (g g^{-1} d^{-1})	LWR (g g^{-1})	SLA (cm^2 g^{-1})	LAR (cm^2 g^{-1})	NAR (g m^{-2} d^{-1})
C	0.0744 a	0.3817 c	162.33 a	67.18 a	8.51 A
S_1	0.0731 b	0.3970 b	148.58 b	64.71 b	8.41 AB
S_2	0.0672 c	0.4085 a	136.45 c	62.00 c	8.20 B

Values followed by a different letter are significantly different at $P \leq 0.01$ if labelled with different lower case letters. Values followed by a different letter are significantly different at $P \leq 0.05$ if labelled with different upper case letters.

Contrary to LWR, SLA decreased with increasing salinity. There was a relative thickening of the leaves (1/SLA), which was greatest in treatment S_2 as shown in Table 5 where the value of the seasonal average, SLA of S_2 treatment is significantly different from C and S_1

The product of LWR × SLA gave a reduction in leaf area per unit of plant dry matter (LAR) with rising salinity. The LAR of treatment S_2 was always significantly lower than the control C and S_1. The same significant difference is confirmed by the seasonal average reported in Table 5. During crop development the NAR of S_2 was slightly lower than that of C and S_1 but not significantly. However, the seasonal averages of treatments C and S_1, both were significantly higher than that of treatment S_2 at $P \leq 0.05$ (Table 5).

The energy conversion efficiency (ECE) calculated as reported in Section Soil and crop measurements is a measure of the percentage of solar energy converted into biomass. From the time interval 23–36 DAT, the ECE significantly decreases as salinity increases (Fig. 9). The seasonal average ECE of saline treatments S_1 and S_2 were 10 % and 32 % lower than that of C, respectively. The ECE reduction with increasing salinity is in agreement with the reduction in LAD, ETc and *W*.

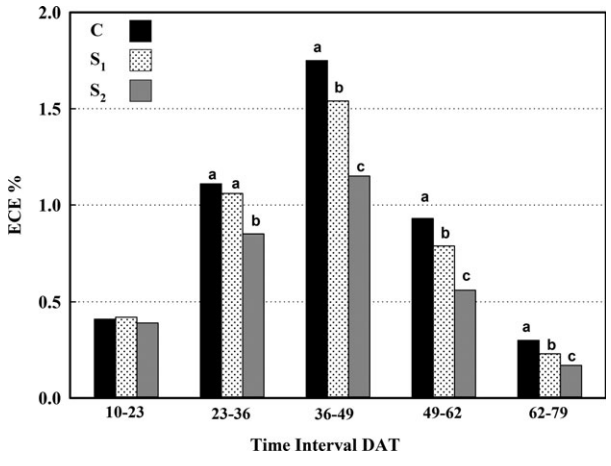

Fig. 9 Energy conversion efficiency (ECE) at different time intervals and for the salinity treatment under study (C = ECw 1.0 dS m^{-1}, S_1 = ECw 2.66 dS m^{-1} and S_2 = ECw 7.03 dS m^{-1}). At each time interval the values indicated by bars are significantly different at $P \leq 0.01$ if labelled with different letters.

Tolerance to salinity

In a previous study (Huang et al. 2012), the response of the cultivar Huanghemi to soil salinity was evaluated by applying the linear model $Y_r = 100 - b(EC_e^d - a)$ of Mass and Hoffman. The soil salinity was expressed as the mean seasonal electrical conductivity of the saturate soil paste (EC_e^d) of the 0.0–1.0 m soil layer. The *a* parameter is the critical salinity threshold above which a yield reduction (slope *b*) per unit increase in salinity occur. The Mass and Hoffman coefficients continue to provide the scientific basis for irrigation management guidelines world-wide. However, according to Letey et al. (2011), plants respond to the salinity of the water surrounding the roots (ECs), and therefore, the Mass and Hoffman equation should be calculated as a function of the mean seasonal electrical conductivity of the soil solution of the soil layer 0.0–1.0 m (EC_s^d). However, due the fact that the soil electrical conductivity changes with depth, as shown in Fig. 10, the roots are exposed to different level of salinity. Therefore, the Mass and Hoffman equation was re-calculated as a function of EC_{sw}^d which is the weighted seasonal average of the soil salinity of the soil profile 0.0–1.0 m, with weights taken equal to the crop water uptake in each layer.

In Table 6 and in Fig. 11 we give and compare two equations that evaluate the yield reduction as function of (EC_e^d) and of (EC_{sw}^d).

In our experiment the control treatment C of each year was irrigated with the best available water (ECw = 1.0 dS m^{-1}) and the plot C had the highest yield crop. The relative yield was calculated by dividing observed yield in a given plot and year by the yield observed in the control plot in the same year. The relative yield was then plotted against the corresponding mean seasonal EC_e^d or EC_{sw}^d. For both equations R^2 was highly significant but the highest R^2 value and the lowest RMSE (root mean square

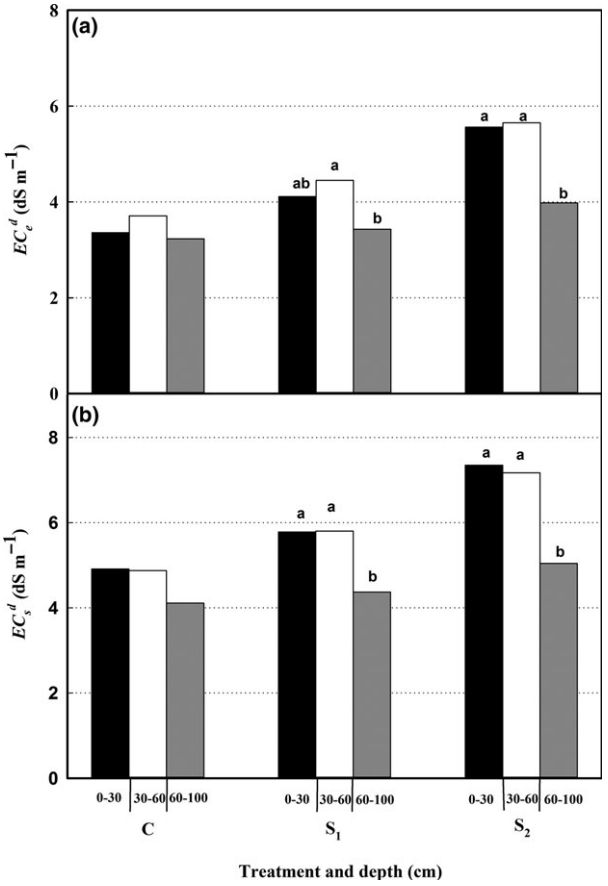

Fig. 10 Variation of the seasonal average of salinity in saturated paste (EC_e^d, Fig. 10a) and of the soil salinity (EC_s^d, Fig. 10b) at different depth and for the different saline treatment (C = ECw 1.0 dS m^{-1}, S_1 = ECw 2.66 dS m^{-1} and S_2 = ECw 7.03 dS m^{-1}). At each saline treatment the values indicated by bars are significantly different at $P \leq 0.01$ if labelled with different letters.

error) of the equation evaluated against (EC_{sw}^d) confirm that Y_r can be better related to (EC_{sw}^d) than to (EC_e^d).

The same linear model was used to estimate (Table 6) the reduction, with increasing soil salinity EC_e^d or with increasing salinity of the soil solution adsorbed EC_{sw}^d, of the relative (r) leaf area duration (LAD_r) shoot dry weight (W_r) and relative crop evapotranspiration (ETc_r). The LAD_r, W_r and ETc_r were normalized as carried out with Y_r. Also for LAD_r W_r and ETc_r, the highest R^2 and the lowest RMSE (Table 6) are the ones obtained with the equation evaluated against (EC_{sw}^d).

The (EC_{sw}^d) threshold value above which the LAD, ETc and W decreased was 4.12, 3.94 and 4.43 dS m^{-1}, respectively. Beyond these thresholds, LAD, ETc and W decreased at the rate of 11.29 %, 8.11 % and 11.22 %, respectively, per unit increase of salinity of the adsorbed soil solution (dS m^{-1}). A reduction of the 50 % of LAD, ETc and W was estimated at 8.55, 10.12 and 8.89 dS m^{-1}, respectively.

Table 6 Relative yield (Y_r), relative total dry matter (W_r), relative leaf area duration (LAD_r) and relative crop evapotranspiration (ETc_r) response at: (i) increasing salinity expressed as weighted seasonal average of the soil salinity for the soil profile 0.0–1.0 m (EC_{sw}^d) with weights taken equal to crop water uptake in each layer, (ii) increasing salinity expressed as (EC_e^d) that is the weighted seasonal average of the ECe for the soil profile 0.0–1.0 m, with weights taken equal to the thickness of each layer. The threshold value (a), the slope (b), the correlation coefficient (R^2), the root mean square error (RMSE) and the value of EC_{sw}^d and EC_e^d at which a reduction of 50 % ($R_{50\%}$) of Y_r; W_r; LAD_r and ETc_r have occurred, are reported

Equation of the linear model	b	a	$R_{50\%}$	R^2	RMSE
$Y_r = 100 - b(EC_e^d - a)$	12.71	2.71	6.64	0.81***	5.04
$W_r = 100 - b(EC_e^d - a)$	13.23	2.99	6.78	0.81***	5.22
$LAD_r = 100 - b(EC_e^d - a)$	12.71	2.65	6.58	0.76***	5.77
$ETc_r = 100 - b(EC_e^d - a)$	9.82	2.64	7.72	0.81***	3.94
$Y_r = 100 - b(EC_{sw}^d - a)$	10.30	3.99	8.84	0.83***	4.83
$W_r = 100 - b(EC_{sw}^d - a)$	11.22	4.43	8.89	0.91***	3.68
$LAD_r = 100 - b(EC_{sw}^d - a)$	11.29	4.12	8.55	0.94***	2.90
$ETc_r = 100 - b(EC_{sw}^d - a)$	8.11	3.94	10.12	0.85***	3.42

***P ≤ 0.001.

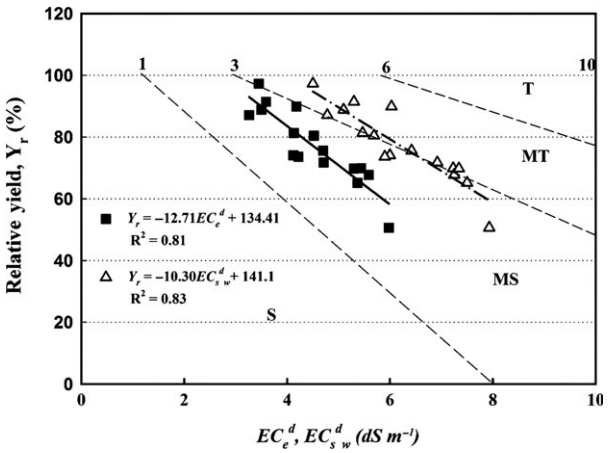

Fig. 11 Relative yield (Y_r) response at increasing soil salinity expressed as the weighted seasonal average of the saturated paste for the soil profile (0.0–1.0 m), with weights taken equal to the thickness of each layer (■) EC_e^d. Moreover, relative yield (Y_r) response at increasing of soil salinity expressed as the weighted seasonal average of soil salinity in the soil profile (0.0–1.0 m), with weights taken equal to crop water uptake in each layer (Δ) EC_{sw}^d. The areas indicated as S, MS, MT and T correspond to Sensitive, Moderately Sensitive, Moderately Tolerant and Tolerant according to the Maas-Hoffman model.

These results show that the threshold values (a) increased in the order $LAD_r = ETc_r < W_r$, while the slope (b) decreased in the order $LAD_r = W_r > ETc_r$. Therefore, considering also the values at which a 50 % of reduction occurs, the leaves (LAD) were more sensitive than W to salinity, and W was more sensitive to salinity than ETc.

Ionic composition

For the ion concentrations of plant tissues measured in 2007 and 2008, statistical processing was carried out for each ion, arranging the 2 years' measurements according to a virtual split-splot design (Gomez and Gomez 1984). The following set-up was used: saline treatments (C, S_1 and S_2) in the main plot, position on the plant (apical leaf = La, basal leaf = Lb, apical stem = Sa, basal stem = Sb and root = R) in the subplot, harvest time (23, 49 and 79 DAT) in the subplot and years in elementary plots. For all treatments the homogeneity of the error variance for the 2 years and the absence of interaction with year allowed the 2-year data to be directly presented and discussed.

The seasonal average ionic concentration in each treatment significantly increased with salinity for Na and K (column of the mean $\bar{m}$ in Table 7) while no significant differences were observed for Cl, Ca and Mg. Table 7 also reports the averages of the treatments separately for the different plant parts (row of average $\bar{m}$). Importantly, older basal stems and leaves, other conditions being equal, were exposed to salinity longer than the young plant parts (apical stems and leaves).

The highest concentrations of K and Cl are observed in the basal stems and in significantly decreasing order in the apical stems and root. Also for Na the highest concentration was observed in the basal stems and, in significantly decreasing order, the roots and then the apical stems. By contrast, for Ca and Mg, the highest concentrations were observed in the basal leaves, followed by the apical leaves, basal stems and apical stems. For Ca and Mg the lowest concentration is in the roots while for Na in the apical

Table 7 Seasonal average ionic concentration of Na, K, Cl, Ca and Mg, in % of dry weight (d.w.) in different plant parts (La = apical leaves, Lb = basal leaves, Sa = apical stems, Sb = basal stems, *R* = roots), under different saline treatments (C = water at 0.8 g l^{-1}, ECw 1.0 dS m^{-1}, S_1 = water at 2 g l^{-1}, ECw 2.66 dS m^{-1} and S_2 = water at 5 g l^{-1}, ECw 7.03 dS m^{-1}) and the difference between the extreme treatments (S_2–C)

Treatment	La	Lb	Sa	Sb	*R*	$\bar{m}$
Concentration of Na^+ (d.w. %)						
C	0.14	0.17	0.46	0.83	0.69	0.46 c
S_1	0.22	0.21	0.66	1.05	0.75	0.58 b
S_2	0.29	0.50	0.75	1.41	1.02	0.79 a
$\bar{m}$	0.22 e	0.29 d	0.62 c	1.10 a	0.82 b	
S_2–C	0.15**	0.33**	0.29**	0.58**	0.33**	
Concentration of K^+ (d.w. %)						
C	1.60	1.18	3.10	3.75	2.68	2.46 b
S_1	1.80	1.10	3.45	3.85	3.05	2.65 b
S_2	2.30	1.40	4.80	4.80	3.73	3.41 a
$\bar{m}$	1.90 d	1.23 e	3.78 b	4.13a	3.15c	
S_2–C	0.70**	0.22	1.70**	1.05**	1.05**	
Concentration of Cl^- (d.w. %)						
C	1.10	1.09	3.28	5.38	2.50	2.67
S_1	1.20	1.27	3.69	5.18	2.27	2.72
S_2	1.15	1.27	3.71	5.56	2.13	2.76
$\bar{m}$	1.15 d	1.21 d	3.56 b	5.37 a	2.30 c	
S_2–C	0.05	0.18	0.43**	0.18	−0.37**	
Concentration of Ca^{2+} (d.w. %)						
C	1.92	2.70	0.62	1.22	0.52	1.40
S_1	1.55	2.79	0.65	1.15	0.42	1.31
S_2	1.62	2.54	0.51	1.07	0.45	1.24
$\bar{m}$	1.70 b	2.68 a	0.59 d	1.15 c	0.46 e	
S_2–C	−0.30**	−0.16	−0.11	−0.15	−0.07	
Concentration of Mg^{2+} (d.w. %)						
C	1.50	2.95	0.79	1.37	0.60	1.44
S_1	1.46	2.97	0.77	1.17	0.57	1.39
S_2	1.23	3.07	0.65	1.22	0.54	1.34
$\bar{m}$	1.40 b	3.00 a	0.74 d	1.25 c	0.57 e	
S_2–C	−0.27**	0.12	−0.14	−0.15	−0.06	

Averages of the treatments (column $\bar{m}$) followed by a different letter are significantly different at $P \leq 0.01$. Values without letters are not significant. Averages of the plant part (row $\bar{m}$) followed by a different letter are significantly different at $P \leq 0.01$. The difference in ionic concentration (S_2–C) for each plant part is significant for $P \leq 0.01$ if accompanied by **.

leaves and for K in the basal leaves. The Cl concentration is not significantly different between basal and apical leaves.

The interaction saline treatment × position on the plant (first three rows of each box in Table 7) is significant for all the ions analysed and is due to a different response to salinity of the different plant parts. Therefore, we prefer to discuss the interaction by focusing on this different response and statistically analysing the difference ionic concentration between the treatments of each plant part. In Table 7, the differences between the extreme treatments S_2–C are reported and marked with ** asterisks if significant for $P \leq 0.01$.

The greater accumulation of Na, in accordance with Navarro et al. (2000), was in the basal part of the plant (stems and roots). The smallest accumulation in absolute value occurred in the apical leaves which also had the lowest ionic concentration.

The highest K accumulation was in the apical stems followed by the basal stems and roots. No significant accumulation occurred in the basal leaves which also had the lowest ionic concentration, while there was a significant increase in K also in the apical, hence the youngest, leaves. The high K concentration in the stems the plants ensured, even in a saline environment, the necessary K supply to the leaves, especially in the youngest ones (Salibsury and Ross 1988). An increase in K in leaves as salinity increased was observed by Cabot et al. (2009) in beans. Seemann and Critchley (1985) also found in beans an increase in K concentrations with an increase in NaCl concentration in the solution. By contrast, in the melon cultivar Galia, Navarro et al. (2000) found with an increase in salinity a decrease in K content in all plant parts except in the young leaves. Also del Amor et al. (1999) found a significant reduction in K with salinity, especially under longer exposure to salinity.

The greater or lesser concentration of K under saline condition is then a controversial question and this was confirmed by Shabala and Cuin (2007) who under saline condition reported an increase or a decrease of K in the mesophyll in different species.

However, in our experiment in the most saline treatment, S_2, at the higher concentration of K observed in the apical (2.30) compared to the basal leaves (1.40), a lower concentration of Na was observed in the apical leaves (0.29) compared to the basal (0.50). A significant increase in Cl was observed in the apical stems but not in the leaves, while in the roots a significant decrease was observed with increasing salinity.

The adsorption and transport of Ca and Mg under saline conditions were not significantly reduced. This is an important factor for plant tolerance to salinity because the toxic effect of Na can be mitigated by maintaining a reasonable amount of Ca and Mg (Cramer 2002, Unno et al. 2002).

The ionic concentrations shown in Table 8 are due both to the duration of salt exposure (from 23 to 49 DAT) and to the progressive increase in soil salinity (Fig. 3).

From 23 to 79 DAT, the concentration of all ions increased and at 79 DAT stabilized at the values reached at 49 DAT. The exception is K whose concentration at 79 DAT goes back to the initial value at 23 DAT. However, the difference in K during the crop cycle, albeit significant, decreased. For all the ions except K, the saline treatment × harvest time interaction was not significant. This means that the trend described in Table 8 is common to all ions. For K, instead, the interaction was significant for $P \leq 0.01$ and the values reported in Table 9 indicate that the decrease in concentration observed at 79 DAT in Table 8 was due to treatment C, which is why all the plant parts at 79 DAT always had a significantly lower content of K. By contrast, in treatment S_2, the K concentration increased over time till the last harvest.

Discussion

The seasonal average of the soil salinity EC_s^d to which the plants of the melon cultivars Huanghemi were exposed was 4.58, 5.22 and 6.52 dS m^{-1} for treatments C, S_1 and S_2, respectively. With increasing salinity the osmotic potential $\overline{\psi_\omega^{sw}}$ of the solution adsorbed by the plant decreased significantly in the treatment S_2. Also $\overline{\psi_t}$, except for 62 DAT, decreased with increasing salinity since $\overline{\psi_\omega^{sw}} > \overline{\psi_m}$.

Despite irrigations were applied at intervals of 13 days, the mean seasonal $\overline{\psi_m}$ was on average only 1/3 on $\overline{\psi_t}$ in the control C and was not related to the parameters ETc and W were not correlated with $\overline{\psi_m}$, while the correlation of $\overline{\psi_\omega^{sw}}$

Table 8 Ionic concentration (d.w. %) of Na, K, Cl, Ca and Mg over time (from 23 to 79 DAT). For each ion different letters indicate significant difference at $P \leq 0.01$

DAT	Na^+	K^+	Cl^-	Ca^{2+}	Mg^{2+}
23	0.39 b	2.81 b	2.24 b	0.97 b	1.09 b
49	0.72 a	2.92 a	2.86 a	1.55 a	1.49 a
79	0.74 a	2.78 b	3.35 a	1.43 a	1.60 a

Table 9 Saline treatments × days after thinning (DAT) interaction: K ion concentration (d.w. %) over DAT and for the saline treatment under study. (C = water at 0.8 g l^{-1}, ECw 1.0 dS m^{-1}, S_1 = water at 2 g l^{-1}, ECw 2.66 dS m^{-1} and S_2 = water at 5 g l^{-1}, ECw 7.03 dS m^{-1}). Different letters indicate significant difference at $P \leq 0.01$

Treatment	23DAT	49DAT	79DAT
C	2.61 c	2.68 c	2.08 d
S_1	2.57 c	2.69 c	2.68 c
S_2	3.23 b	3.40 ab	3.60 a

with the same parameters was high. These results suggest that the dominant effect on yield reduction was due to $\overline{\psi_{\omega}^{sw}}$, that is EC_{sw}^{d}, and the Mass–Hoffman describes with a good approximation the salinity impact on crop yield.

The yield reduction with increasing salinity, expressed as the weighted seasonal average of soil salinity for the soil profile 0.0–1.0 m (EC_{sw}^{d}) with weights taken equal to crop water uptake in each layer, that is 10.3 % indicates a higher tolerance of the cultivar than the tolerance estimated when relating Y_r to the soil salinity (EC_{e}^{d}). The ETc reduction is associated to a reduction in leaf area duration (LAD) and a lower accumulation of dry matter (W). A reduced leaf surface means less solar radiation intercepted and hence a lower percentage of solar energy converted into biomass (Arkebauer et al. 1994). In this experiment the cumulative ETc at the end of the crop cycle of treatments S_1 and S_2 was 12 % and 24 % lower than the treatment C, respectively. Similarly, the LAD decreased by 16 % and 33 %, ECE by 10 % and 32 % and W by 13 % and 31 %. The W of treatment S_2 decreased more than the ETc reduction, which resulted in a lower WUE compared to C and S_1. The reduction of ECE with the increase in salinity is mainly attributable to the reduction in leaf surface (Arkebauer et al. 1994) but also to a lower efficiency of the photosynthetic leaf tissues of S_2. Indeed, the seasonal average NAR of treatment S_2 was significantly lower than those of C and S_1.

In this experiment the highest correlation between RGR and LAR ($R^2 = 0.93$***) compared to that between RGR and NAR ($R^2 = 0.42$**) shows that the RGR decrease was caused mainly by the reduction in LAR, that is by the reduced proportion of photosynthesized plant material, and only secondarily, in particular for treatment S_2, also by NAR reduction. Tedeschi et al. (2011) obtained similar results on melon (cultivar Tendral) but in this regard other specific references on melon are lacking. On other species it has been shown (Curtis and Läuchli 1986, Shennan et al. 1987, Bayuelo-Jiménez et al. 2003, Bie et al. 2004 and Ewe and da Silveira Lobo Sternberg 2005) that salinity affects the LAR, that is leaf expansion would be the limiting factor for growth. By contrast, for other authors (Cramer et al. 1990, Bayuelo-Jiménez et al. 2003 and Saied et al. 2005) the limiting factor in growth under salinity stress could be photosynthesis as, again in species other than melon, RGR has been found correlated with NAR but not LAR.

A key role in salt tolerance is played by the adsorption and accumulation of a reasonable quantity of K, Ca and Mg. The elements Ca and Mg regulate many physiological processes that influence both growth and response to environmental stresses (Soussi et al. 2001, Dogan et al. 2010). Their accumulation can mitigate Na toxicity and its inhibitory effect on growth and represents an important factor for the plant tolerance to salinity (Cramer 2002, Unno et al. 2002). Reasonable amounts of Ca and K are also required to maintain the integrity of the cell membrane (Ashraf 2004). K, moreover, is related to stomata regulation which is the main factor of the water balance and nutrient transport in the plant (Marschner 1995, Tuna et al. 2010). Thus, plants that grow in saline environments must procure a sufficient amount of K to counteract the absorption of sodium which is in competition with K (Grattan and Grieve 1999) and ensure the maintenance of the absorption and transport of Ca and Mg.

In this experiment, the higher concentration of K observed in the stems with increasing salinity appears due to a preferential flow of K ions rather than Na in the cells of the stems (Munns 2002). In fact the ratio of the ionic concentration K/Na in the apical stems is 6.7 and 6.4 for the C and S_2 respectively. This would be favoured, by the presence of the Ca and Mg ions whose concentration did not experience a significant reduction under saline conditions (LaHaye and Epstein 1969 and Cramer 2002). Moreover, the highest concentration of K in the apical leaves of treatment S_2 appears enhanced by Na, as reported by Cabot et al. (2009) for bean and Kinraide (1999) for other species. In fact the ratio K/Na of the apical leaves of S_2 was 7.9, so higher than the ratio of 6.7 observed in the apical stems of the C treatment. However, the ratio K/Na of the apical leaves of the C treatment was 11.4. This indicates that the largest adsorption of K was not enough to fully counteract the increase of Na. This is confirmed by the ratio of the ionic concentration of the apical leaves of S_2 vs. the control C: 2.1 for the Na and 1.4 for K.

Conclusion

Several different responses of the melon cultivar Huanghemi to the salinity level were observed. The plants grown under saline condition kept sufficient concentration of Ca and Mg and increased the K concentration that was not sufficient to counter-balance the Na adsorption which content increased under saline conditions. With the increase in salinity the matric potential increased while the total potential decreased due to the high osmotic potential. Consequently, with the increase of salinity water consumption (ETc) decreased. The reduction in ETc is associated to a reduction in leaf area duration (LAD), a reduction in the proportion of photosynthetic surface area but also the transpiration area (LAR) and dry matter accumulation above ground (W). The proportion of assimilates stored in the leaves (LWR) and their relative leaf thickness (1/SLA) also increased.

In the most saline treatment, S_2, a reduction was observed in the photosynthetic efficiency of the leaf tissue (only seasonal average NAR) which, together with the reduction in the proportion of LAR, accentuated the

decrease in energy conversion efficiency (ECE). This led to a significant reduction in relative growth rate (RGR).

If we consider the salinity of the soil solution adsorbed from the plant (EC^{d}_{sw}), that is the one at which the plant is actually exposed, the tolerance of the cultivars Huanghemi to salinity is higher.

We can conclude that the yield loss of melon under saline condition was determined by the increase of Na adsorption and also by the lower water potential.

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