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Sweet pepper production in substrate in response to salinity, nutrient solution management and training system

José S Rubio[1]; Walter E Pereira[2]; Francisco Garcia-Sanchez[1]; Luis Murillo[1]; Antonio L García[3]; Vicente Martínez[1]

[1]Centro de Edafología y Biología Aplicada del Segura, CSIC, Depto. Nutrición Vegetal, Espinardo, Murcia, Espanha; [2]UFPB-CCA, Depto. Ciências Sociais e Fundamentais, 58397-000 Areia-PB; wep@cca.ufpb.br; [3]Depto. Química Agrícola. Facultad de Química. Universidad de Murcia. P.O. Box 4021 Murcia, Espanha

ABSTRACT

The objective of the present study was to evaluate the marketable fruit yield of sweet pepper plants (*Capsicum annuum* cv. Orlando) in function of the management of nutrient solution with training system. Plants were grown on coconut coir dust under greenhouse conditions in the southeast of Spain. A randomized block design in split-split plot with four blocks was used to test the effect of the nutrient solution strength (full or half-strength Hoagland nutrient solution), training system (two and three stems per plant) and water salinity (saline and non-saline) on total and marketable yield, fruit quality, and fruit mineral concentration. Salt treatment decreased fruit yield by decreasing the fruit fresh weight but not the number of fruits per plant. Under saline and non-saline conditions, the higher yield of fruits was obtained in plants watered with half-strength Hoagland solution, and grown with three stems per plant. Blossom end rot incidence increased under saline conditions or using full-strength Hoagland solution, but decreased with the combination of half-strength Hoagland solution and three-stem training system. Salt treatment also decreased fruit quality in all the treatments due to a decrease in PO_2^-, SO_4^{2-}, $Fe^{2+;3+}$, $Cu^{1+;2+}$ and Mn^{2+} concentrations, and fruit shape index. Likewise, plants exposed to salinity and watered with half-strength Hoagland solution and trained with three stems showed a reduction in juice glucose and fructose concentration. Based on these results, an increase of the marketable fruit yield could be obtained under non or moderate saline conditions with the implementation of suitable culture practices.

Keywords: *Capsicum annuum*, soilless, crop culture practices, marketable fruit yield.

RESUMO

Produção de pimentão cultivado em substrato em resposta à salinidade, manejo da solução nutritiva e sistema de condução

Este experimento teve como objetivo avaliar a produção comercial de pimentão doce (*Capsicum annuum* cv. Orlando) em função do manejo da solução nutritiva, da salinidade e do sistema de condução. As plantas de pimentão doce foram cultivadas em substrato de fibra de coco em casa de vegetação no sudeste da Espanha. Um experimento no delineamento de blocos casualizados em parcelas sub-subdivididas, com quatro repetições, foi utilizado para testar os efeitos da concentração da solução nutritiva (Hoagland completa ou meia-força iônica), sistemas de condução (dois ou três ramos por planta) e a salinidade da água (salina ou não salina) sobre o rendimento total e comercial, a qualidade dos frutos e a concentração de nutrientes minerais nos frutos. A salinidade diminuiu o rendimento dos frutos devido à menor massa da matéria fresca dos frutos, mas não diminuiu o número de frutos por planta. Tanto na presença como na ausência da salinidade, o maior rendimento de frutos foi obtido pelas plantas irrigadas com solução nutritiva de Hoagland meia força e conduzidas com três hastes por planta. A incidência de podridão apical aumentou com o aumento da condutibilidade elétrica na solução nutritiva e diminuiu na solução de Hoagland meia força. A salinidade diminuiu a qualidade dos frutos em todos os tratamentos devido à diminuição nos teores de PO_4^{2-}, SO_4^{2-}, $Fe^{2+;3+}$, $Cu^{1+;2+}$ e Mn^{2+}, além do índice de formato do fruto. Da mesma maneira, as plantas salinizadas e irrigadas com a solução de Hoagland meia força e conduzidas com três hastes apresentaram menor concentração de glicose e de frutose na polpa do fruto. Com base nestes resultados, o rendimento comercial poderia ser aumentado com água não salina ou com salinidade moderada mediante a implementação de práticas culturais adequadas.

Palavras-chave: *Capsicum annuum*, hidroponia, práticas culturais, rendimento comercial do fruto.

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Season and off-season production of sweet pepper are mainly located in the Mediterranean basin (i.e. southeast of Spain and Israel). These semi-arid and arid regions are characterized by severe drought episodes that force growers to use poor quality water to satisfy water requirements for agriculture. The use of such water increases the soil salinization that together with the high incidence of nematodes and weed pressure in the soil causes important damages in the crops (Puigdefabregas & Mendizabal, 1998; Gilreath *et al*., 2005). To overcome these problems the implementation of soilless culture is mandatory. On the other hand, pepper is considered a salt sensitive species with a salinity threshold in the nutrient solution (NS) of about 2.8 dS m^{-1} for soilless culture (Sonneveld & Vanderburg, 1991). Irrigation water with an electrical conductivity (EC) higher than this level increases the blossom-end rot incidence (BER) and decreases the fruit number per plant and fruit weight, leading to a decrease of marketable fruit yield (Rubio *et al*., 2009; Chartzoulakis

& Klapaki, 2000). While attempts to improve the salt tolerance of crops through conventional breeding programs have very limited success (Rozema & Flowers, 2008), most growers still rely on crop management practices to ameliorate salinity problems. Some studies have indicated that the use of saline water requires the improvement of irrigation management in order to maintain salt levels in the root zone below the threshold values (Oster, 1994; Rubio *et al*., 2010a). Although a decrease in the concentration of the NS could help to reduce salt levels in the root zone. Studies about zucchini squash (*Cucurbita pepo*) and salvia (*Salvia splendens* F.) have shown that decreasing the NS concentration reduces fruit yield and growth (Rouphael & Colla, 2009; Kang & van Lersel, 2004). Coincidentally, a decrease in nutrient uptake was observed by decreasing the concentration of nutrient in the irrigation solution. One interesting possibility is the increase of irrigation frequency when the concentration of the NS is reduced in order to synchronize nutrients and water uptakes by the plant with the supply of nutrients and water by the irrigation system (Klaring, 2001).

Blossom-end rot is a common physiopathy affecting sweet pepper fruits and provoking elevated loss of marketable fruits. It starts with a local Ca^{2+} deficiency in the period of rapid fruit expansion (Ho & White, 2005; Rubio *et al*., 2009). High nutrient conductivity increase BER incidence since they contribute to reduce water uptake by roots and then Ca^{2+} allocation to the fruit (Tadesse *et al*., 1999). Plants with high leaf area should then show a reduction in BER incidence. Training the plants with two or three stems helps to optimize greenhouse cropping conditions, solar radiation interception and marketable quality (Salas *et al*., 2006; Lee & Liao, 2007). This kind of culture severely affects the leaf area index, and probably it influences the plant ability to uptake water and nutrients from the root medium, specially when CO_2 and light are not limiting factors.

The objective of the present study was evaluate marketable fruit yield of sweet pepper plants grown on coconut coir dust, by combining the management of nutrient solution with training system and salinity.

MATERIAL AND METHODS

Greenhouse experiments were conducted in 2002 at Santomera Experimental Station (Murcia, Spain) during winter, spring, and early summer. During the culture cycle (172 days), the temperature ranged between 16-32ºC and the relative humidity between 55-90% (day/night). Sweet pepper seedlings (*Capsicum annuum* cv. Orlando) from a commercial nursery (Viveros "Mar Menor", Torre Pacheco, Murcia, Spain) were transplanted to coconut coir dust bags (120 cm length x 22 cm width x 15 cm height; 40 L of capacity) on December 13. Three plants per bag were placed with 0.33 m between plants in the row and 1.2 m between rows. Transplanted plants bearing two true leaves were used in all cases. The averages of plant height and shoot weight were of 15 cm and 4.4±0.32 g, respectively. A line of emitters was located by each row of plants (one emitter per plant). The emitters had a discharge flow of 2 L h^{-1}. The Hoagland solution was performed using water from the Tajo-Segura aqueduct mixed with commercial fertilizers (Rubio *et al*., 2010a). The resulting nutrient solution had the following composition (mM): 16 NO_3^-, 1.5 $H_2PO_4^-$, 0.5 HCO_3^-, 7 K^+, 4 Ca^{2+} and 2 Mg^{2+}. The composition of micronutrients was as follows (mg L^{-1}): 1.8 Fe, 0.7 Mn, 0.07 Cu, 0.12 Zn, 0.15 B and 0.05 Mo. In all treatments, the pH was kept within the range of 5.5 to 6.0 by adding HNO_3. The day before transplanting, coconut bags were saturated with full-strength Hoagland solution, and then left without irrigation for the following week.

The experiment consisted of eight treatments obtained by a 2 x 2 x 2 combination: two NaCl concentrations (0 mM NaCl or 15 mM NaCl), two nutritive solution (NS) strength (full-strength Hoagland solution, applied in four events per day, or half-strength Hoagland solution applied in eight events per day) and two training systems (plant grown with two or three stems). Treatments were allocated in a randomized block design in split-split plot (Little & Hills, 1976), with four blocks. The NaCl concentrations were the main plots, the strength of NS were the subplots, and finally the training systems were the sub-subplots. The experimental unit was constituted by six plants.

The final electrical conductivity (EC) in full-strength Hoagland solutions were 2.3 dSm^{-1} (when combined with 0 mM NaCl) and 3.8 dSm^{-1} (in combination with 15 mM NaCl). In the cases of half-strength Hoagland solutions the final electrical conductivities were 1.7 dSm^{-1} (without NaCl) and 3.2 dSm^{-1} (combined with 15 mM NaCl). After one week with no irrigation, full and half-strength Hoagland solutions were applied. NaCl was added 25 days after then, to establish the salinized treatments.

All treatments received daily the same amount of water. Then, plants watered with full-strength Hoagland solution received the double amount per event than those watered with half-strenth Hoagland solution. Irrigation timing and doses were scheduled using a computer: plants receiving full-strength Hoagland solution were irrigated at 7.00, 11.00, 15.00 and 19.00 h; plants receiving half-strength Hoagland solution were irrigated at 7.00, 09.00, 11.00, 12.00, 13.00, 14.00, 16.00, and 18.00 h. The EC of the NS for each treatment was kept constant through the culture cycle. The amount of daily water increases periodically to ensure that EC of the drainage solution did not exceed 130% of EC from the NS.

Red fruits were selectively harvested weekly from 70 days after transplanting until the end of the experiment. In addition, at the end of the experiment, one representative marketable pepper fruit (18 fruits) was selected from different plants and used for determining fruit quality. Yield was determined by counting and weighing all fruits on each plant. Marketable fruit yield was determined according to the color, the health state, the shape, and the weight (Navarro *et al*., 2002). Fruits weighing less than 100 g, and those affected by blossom end rot were counted separately. Fruit firmness was determined on three discs of the skin surface in the equatorial area of fruit pulp using a penetrometer fitted with an 8-mm diameter probe (Bertuzzi FT 011). Fruit shape index (FSI) was defined by the equatorial to longitudinal length ratio. The selected fruits were then cut and the pulp thickness was measured using an electronic digital calliper.

Chemical fruit quality was determined in the edible portion of the same fruit sample used for the physical analyses (Rubio *et al*., 2009). This determination was done by liquefying and filtering the fruits. The pH, the content of total soluble solids (TSS), and titratable acidity (TA) were then measured. TSS was determined using an Atago N1 refractometer and expressed as ºBrix at 20ºC. Titratable acidity was assayed by potentiometric titrations with 0.1 N NaOH to pH 8.1 and results were expressed as a percentage of citric acid in the juice. Juice aliquots were stored at -80ºC until determination of soluble sugar. Fructose, glucose, and sucrose concentrations were determined by HPLC (Merck-Hitachi, Tokyo, Japan), using a Tracer carbohydrate 5 µm 25x0.46 column (Teknokroma, Barcelona, Spain) coupled with a differential refractometer detector (Flores *et al*., 2004). The mobile phase was acetonitrile:water (3:1) with a flow rate of 0.9 mL min^{-1}.

The mineral composition of fruit was determined in six replicates per treatment (three fully ripened fruits each replicate). Totally expanded leaf tissue was also sampled in 8 different plants per treatment at day 64 after transplanting. Fruits and leaves were dried at 70ºC until constant weight, digested with HNO_3-$HClO_4$ (2:1), and concentrations of K^+, Na^+, Ca, Mg^{2+}, $Fe^{2+;3+}$, Mn^{2+}, $Cu^{1+;2+}$, and Zn^{2+} were determined by atomic absorption spectrometry (Perkin-Elmer 5500, Waltham, MA, USA). PO_4^{2-}, Cl^- and SO_4^{2-} were extracted from dry tissue with distilled water and determined by ion chromatography, using conductivity detection (Dionex DX-100, Sunnyvale, CA, USA), an Ionpac AG12A guard column, and an Ionpac AS12A analytical column. The mobile phase was 2.7 mmol L^{-1} Na_2CO_3/0.3 mmol L^{-1} $NaHCO_3$.

Data were subjected to analysis of variance (three-way ANOVA; SPSS statistical package, Chicago, USA). When significant differences at $p<0.05$ were obtained in the interaction, mean separations were done using Duncan's multiple range test. No significant differences were observed in the training system for the case of fruit quality; therefore the data was presented regardless this main factor.

RESULTS AND DISCUSSION

The amount of NS applied per plant and per day ranged from 0.5 L/plant/day at the beginning of the culture cycle to 3.8 L/plant/day at the end of the culture cycle (172 days after transplanting). It resulted in 348 L of NS applied per plant, for each treatment. This amount of NS was enough to maintain the EC of the drainage solution lower than 130% of the EC of the NS. Since nutrient

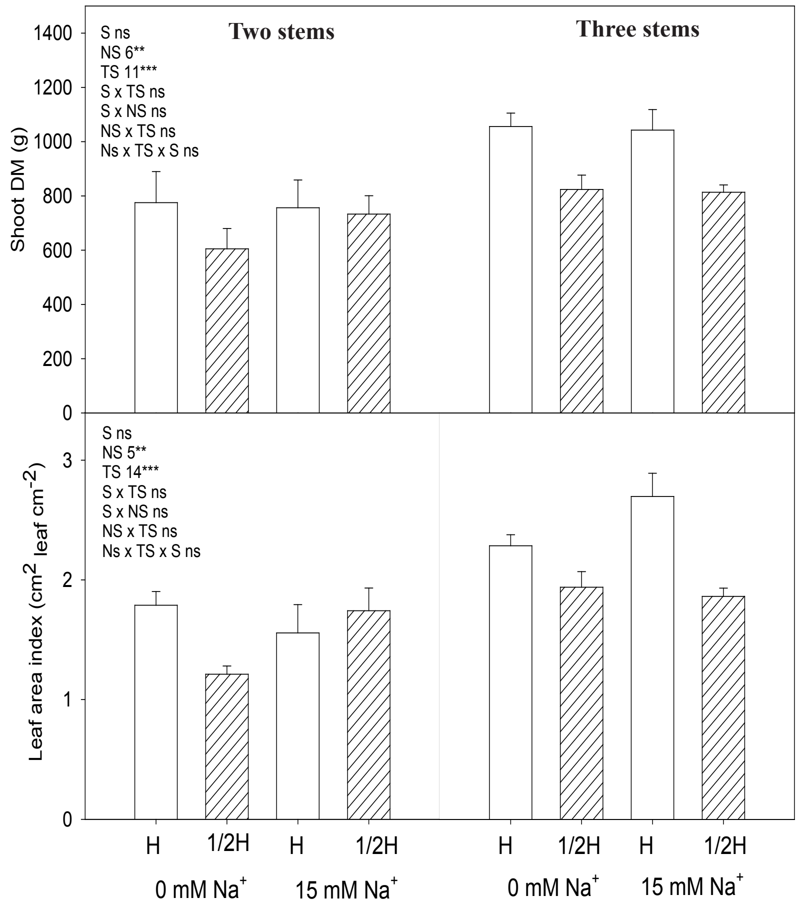

Figure 1. Shoot (stem + leaves) dry matter (g/plant) and leaf area index (cm^2 leaf cm^{-2}) at the end of the experimental period of pepper plants grown with two salt treatments (S; 0 and (15 mol L^{-1} of NaCl) combined with two nutrient solutions (NS; full (H) and half-strength (½ H) Hoagland) and two training systems (TS; 2 or 3 stems per plant). Vertical bars indicate the standard error of the mean (n = 6) (massa da matéria seca da parte aérea (ramos + folhas) (g/planta) e índice da área foliar (cm^2 cm^{-2} da folha) no fim do período experimental de plantas de pimentão crescidas com dois tratamentos de sal (S; 0 e 15 mol L^{-1} de NaCl) combinados com duas soluções nutritivas (NS; Hoagland e ½ Hoagland) e dois sistemas de condução (TS; 2 ou 3 hastes por planta). As barras verticais indicam o erro padrão da meia (n = 6).
** and ***= significant differences between means at 1% and 0,1% of probability, respectively, according to Duncan's multiple range test; ns= non-significant (** e ***= diferenças significativas entre médias a 1% e 0,1% de probabilidade, respectivamente, pelo teste de Duncan; ns= não significativo).

Table 1. Yield, number of fruits per plant and mean fruit weight for total and marketable yield, and blossom end rot of pepper plants submitted to salinity, nutrient solutions management (full and half-strength Hoagland) and two training systems (rendimento, número de frutos por planta e peso médio do fruto para a produção total e comercial, e podridão apical de pimentão submetido a salinidade, manejo da solução nutritiva (Hoagland e ½ Hoagland) e sistema de condução). Murcia, CSIC, 2002.

Nutrient solution	Training system	NaCl (mM)	Total yield: Yield (kg/plant)	Total yield: Nº fruits/plant	Total yield: Mean fruit weight (g)	Blossom end rot (%)
Full-strength Hoagland	2	0	1.91a	14a	136.0a	11.1a
	2	15	1.20a	13a	92.3a	42.5a
	3	0	2.50a	20a	125.0a	16.5a
	3	15	1.70a	18a	94.4a	40.1a
Half-strength Hoagland	2	0	1.74a	13a	133.0a	11.5a
	2	15	1.60a	14a	114.0a	25.8a
	3	0	2.85a	17a	167.0a	6.7a
	3	15	2.10a	19a	110.0a	15.9a
Analysis of variance						
Salinity			***	ns	***	**
Nutrient solution			*	ns	***	**
Training system			***	***	ns	ns
Salinity x training system			ns	ns	ns	ns
Salinity x nutrient solution			*	ns	ns	*
Training system x nutrient solution			ns	ns	ns	*
Salinity x nutrient solution x training system			ns	ns	ns	ns

Nutrient solution	Training system	NaCl (mM)	Marketable yield: Yield (kg/plant)	Marketable yield: Nº fruits/plant	Marketable yield: Mean fruit weight (g)
Full-strength Hoagland	2	0	1.68a	7.12b	240a
	2	15	0.65a	3.21d	216a
	3	0	2.00a	10.10a	200a
	3	15	0.90a	5.24c	180a
Half-strength Hoagland	2	0	1.46a	6.93bc	208a
	2	15	1.10a	6.41bc	183a
	3	0	2.25a	10.40a	225a
	3	15	1.74a	8.82ab	193a
Analysis of variance					
Salinity			***	***	***
Nutrient solution			**	*	*
Training system			***	*	ns
Salinity x training system			ns	ns	ns
Salinity x nutrient solution			**	*	ns
Training system x nutrient solution			*	ns	*
Salinity x nutrient solution x training system			ns	*	ns

*, ** and ***= significant differences between means at 0.05, 0.01, and 0.001 levels of probability, respectively; ns= non-significant. Means with different letters are significantly different ($p<0.05$) according to Duncan's multiple range test. Values are means of fruits harvested in 24 plants (*, ** e ***= diferenças significativas entre médias a 5%, 1% e 0,1% de probabilidade, respectivamente; ns= não significativo. Medias com letras diferentes são significativamente diferentes ($p<0,05$) pelo teste de Duncan. Os valores são médias de frutos colhidos em 24 plantas).

solution was made using water showing a uniform nutrient concentration, the EC that it provided to plants was constant throughout the experimental period. However, the drainage solution showed average ECs of 2.21±0.43, 2.99±0.57, 4.16±0.78 and 4.83±1.02 dSm^{-1} for the treatments with 1.7 (half-strength Hoagland, non-salt), 2.3 (full-strength Hoagland, non-salt), 3.2 (half-strength Hoagland, 15 mM NaCl) and 3.8 (full-strength Hoagland, 15 mM NaCl) dSm^{-1} in the NS, respectively. These values show the expected differences caused by the presence of NaCl in the NS.

Table 2. Leaf mineral concentration (g/kg/dry weight) at 64 days after transplanting in pepper plants submitted to salinity and nutrient solutions management (concentração de minerais (g/kg/ms) em folhas de pimentão, 64 dias após o transplante, submetido a salinidade e manejo da solução nutritiva). Murcia, CSIC, 2002.

Nutrient solution	NaCl	Cl^-	Na^+	Ca^{2+}
Full-strength Hoagland	0	2.45±0.20 a	0.079±0.003 a	30.3±1.42 c
	15	5.87±0.34 a	0.130±0.007 a	28.5±0.55 c
Half-strength Hoagland	0	2.25±0.22 a	0.080±0.004 a	33.4±1.26 b
	15	6.67±0.34 a	0.142±0.006 a	35.6±1.42 a
		Analysis of variance (F values)		
Salinity		***	***	ns
Nutrient solution		ns	ns	***
Salinity x nutrient solution		ns	ns	**

*, ** and ***= significant differences between means at 0.05, 0.01, and 0.001 levels of probability, respectively; ns= non-significant. Means with different letters are significantly different (p<0.05) according to Duncan's multiple range test. Values are means of eight samples (*, ** e ***= diferenças significativas entre médias a 5%, 1% e 0,1% de probabilidade, respectivamente; ns= não significativo. Medias com letras diferentes são significativamente diferentes (p<0,05) pelo teste de Duncan. Os valores são médias de oito amostras).

Table 3. Fruit mineral concentration of pepper plants submitted to salinity and nutrient solutions management (concentração de minerais no fruto de pimentão submetido a salinidade e manejo da solução nutritiva). Murcia, CSIC, 2002.

Nutrient solution	NaCl	Cl^-	PO_4^{2-}	SO_4^{2-}	Na^+	Ca^{2+}	K^+
		(g/kg/dry weight)					
Full-strength Hoagland	0	0.24b	0.92a	0.15a	0.07c	0.30b	21.0a
	15	0.30a	0.84a	0.16a	0.16b	0.52a	22.8a
Half-strength Hoagland	0	0.13c	0.81a	0.13a	0.06c	0.45a	21.2a
	15	0.23b	0.79a	0.13a	0.21a	0.46a	21.3a
		Analysis of variance (F values)					
Salinity		***	*	ns	***	***	ns
Nutrient solution		***	***	**	*	ns	ns
Salinity x nutrient solution		*	ns	ns	**	***	ns

Nutrient solution	NaCl	$Fe^{2+;3+}$	$Cu^{1+;2+}$	Mn^{2+}	Zn^{2+}
		(mg/kg/dry weight)			
Full-strength Hoagland	0	23.4a	8.90a	23.1a	17.0a
	15	16.9a	7.63a	17.0a	19.0a
Half-strength Hoagland	0	23.4a	8.90a	28.6a	16.3a
	15	21.6a	7.63a	20.3a	18.3a
		Analysis of variance (F values)			
Salinity		***	**	***	***
Nutrient solution		*	ns	**	ns
Salinity x nutrient solution		*	ns	ns	ns

*, ** and ***= significant differences between means at 0.05, 0.01, and 0.001 levels of probability, respectively; ns= non-significant. Means with different letters are significantly different (p<0.05) according to Duncan's multiple range test. Values are means of 18 fruits (*, ** e ***= diferenças significativas entre médias a 5%, 1% e 0,1% de probabilidade, respectivamente; ns= não significativo. Medias com letras diferentes são significativamente diferentes (p<0,05) pelo teste de Duncan. Os valores são médias de 18 frutos).

Regardless the saline condition our experiment suggests that the effects of NS and training system combination are significantly important to obtain high fruit yield in pepper plants grown in protected and soilless cultivation system. Considering the total above-ground biomass (shoot and total fruits) each of the three factors studied has different effects; i) salinity did not affect shoot dry matter production (Figure 1) but affected total fruit yield (Table 1); ii) using half-strength Hoagland solution compared to full-strength Hoagland solution decreased shoot dry matter production and increased total fruit yield by increasing mean fruit weight; and iii) plants trained with three stems compared to plants trained with two stems increased both shoot dry matter and total fruit yield by increasing the number of fruits per plant.

Under non-saline conditions, plants grown with three stems and watered with half-strength Hoagland solution increased total and marketable fruit yield compared to the rest of treatments assayed (Table 1). In addition, this treatment showed the highest percentage of extra fruits (11%) (data not shown) and the lowest percentage of BER. The higher yield observed with these treatments could have been due to the following: i) Plants did not show nutrient deficiencies (Table 2) and growth was sustained as indicated by the higher shoot biomass and LAI (Figure 1), which may have enhanced photosynthesis and carbon gain (Nerson, 2002) and ii) the EC of the irrigation solution in plants receiving half-strength Hoagland solution was 0.7 dSm^{-1} lower than in plants receiving full-strength Hoagland solution which may have improved the overall water status in the plant. Finally, it may have enhanced the Ca^{2+} translocation to the fruit tip in the period of rapid fruit expansion, when the susceptibility of developing BER is higher (Ho & White, 2005). In fact, plants from non-saline conditions exhibited an increase in the leaf and fruit Ca^{2+} concentration at higher irrigation frequency (Table 2 and 3, respectively).

Salinity was induced by adding 15 mM NaCl to the NS. The latter is a representative amount of NaCl concentration found in the groundwater of the southeast of Spain. Under these conditions, total fruit yield decreased in all treatments to an extent regulated by the NS employed (Table 1). Plants watered with saline half-strength

Table 4. Values of pH, acidity, total soluble solids, firmness, fruit shape index, and fructose and glucose concentrations in fruit juice of pepper plants submitted to salinity and nutrient solutions management (valores de pH, acidez titulável, sólidos solúveis totais, firmeza, índice de formato do fruto e concentrações de frutose e glicose no suco do fruto de pimentão submetido a salinidade e manejo da solução nutritiva). Murcia, CSIC, 2002.

Nutrient solution	NaCl (mM)	pH	Citric acid (g/100 mL)	Total soluble solids (⁰Brix)	Firmness (N/cm^2)	Fruit shape index	Fructose (g/L)	Glucose (g/L)
Full-strength Hoagland	0	5.17a	3.52a	10.07a	3.91a	7.54a	34.78a	29.92a
	15	5.14a	3.78a	9.88a	3.94a	6.60a	35.14a	31.27a
Half-strength Hoagland	0	5.09a	3.48a	9.23a	4.06a	7.70a	35.52a	30.05a
	15	5.13a	3.47a	9.73a	3.48a	6.82a	30.20b	25.90b
Analysis of variance (F values)								
Salinity		ns	ns	ns	ns	***	ns	ns
Nutrient solution		ns	ns	ns	ns	ns	ns	ns
Salinity x Nutrient solution		ns	ns	ns	ns	ns	*	*

* and ***= significant differences between means at 0.05 and 0.001 levels of probability, respectively; ns= non-significant. Means with different letters are significantly different ($p<0.05$) according to Duncan's multiple range test. Values are means of six replicates (each replicate contained 3 fruits) (*, ** e ***= diferenças significativas entre médias a 5%, 1% e 0,1% de probabilidade, respectivamente; ns= não significativo. Medias com letras diferentes são significativamente diferentes ($p<0,05$) pelo teste de Duncan. Os valores são médias de 6 frutos).

Hoagland solution (EC 3.2 dS m^{-1}) had a lower fruit yield reduction than plants watered with saline full-strength Hoagland solution (EC 3.8 dS m^{-1}). Total yield reduction was due to a decrease in the mean fruit weight but not in the number of fruits per plant. In pepper plants, increasing the EC in the NS decreases linearly the fruit yield (Navarro *et al.*, 2002). Salinities up to 7 dS m^{-1} cause a fruit yield declination due to a reduction in the mean fruit weight. When the salinity is higher than 7 dS m^{-1}, the number of fruits per plant is also decreased (Chartzoulkis & Klapaki, 2000). Results obtained in this work showed an increase in leaf Cl^- and Na^+ concentrations when measured in saline-treated plants, regardless NS (Table 2). In pepper plants, aside from the toxic effect by increasing Cl^- and Na^+ leaf concentrations (Bethke & Drew, 1992), the osmotic effect induce decreases in yield and growth since saline-treated peppers are not osmotically able to keep an adequate leaf water status (Rubio *et al.*, 2010b). Saline plants in half-strength Hoagland solution with two stems had a lower yield reduction (8% relative to non-saline treatment) than those with three stems (26%) (Table 1). However, from an agronomic point of view and according to the absolute term (1.6 and 2.1 kg $plant^{-1}$ for salinized plants with two and three stems, respectively), pepper plants grown in half-strength Hoagland solution and three stems may be a good technique for growing pepper plants under saline conditions.

In pepper plants, marketable yield is usually about 60-80% from the total yield. This reduction is mainly due to BER incidence (Silber *et al.*, 2005). Under non-saline conditions, marketable fruit yield was about 85% from the total fruit yield, whereas under saline conditions it was about 55% and 76% when plants were watered with full-strength and half-strength Hoagland solutions, respectively (Table 1). BER incidence was the main cause of marketable fruit yield reduction. The increase of salinity in the root medium enhanced the incidence of BER in fruits of tomato and pepper (Adams & Ho, 1992; Rubio *et al.*, 2009). Under non-saline conditions, the predominant cause of BER is that the calcium translocation to the fruit tip is inadequate for the rapid fruit expansion (Ho & White, 2005). However, under saline conditions, physiological and biochemical mechanisms leading to BER incidence are not yet clear. Aktas *et al.* (2005) and Turhan *et al.* (2006) pointed out that generation of oxygen free radicals in the apoplast may contribute to the appearance of BER symptoms. We suggest that the Ca^{2+} status during the period of rapid fruit expansion is the main cause of BER incidence in saline conditions. Although salinity in the root medium depresses the translocation of water and Ca^{2+} to the fruit tip during the phase of rapid fruit expansion (Rubio *et al.*, 2009), an increase in irrigation frequency and leaf area index (three-stem training system) could improve both water and Ca^{2+} translocation to the young fruit, diminishing the BER appearance and increasing marketable fruit yield. This is supported by the observed increase in the leaf Ca^{2+} concentration even under saline conditions (Table 2).

Salt stress effect on mineral content in horticultural crops has been studied due to the impact on human nutrition (Lopez-Berenguer *et al.*, 2009). The data showed that sweet pepper fruit mineral concentration is affected by the presence of NaCl in the root medium and the nutrient solution concentration (Table 3). The moderate salinity applied increased Cl^-, Na^+ and Zn^{2+} concentrations in juice with respect to those fruits watered without NaCl. The highest fruit Cl^- and Na^+ concentrations were measured in fruits from plants watered with full-strength Hoagland and half-strength Hoagland solution, respectively. Salinity treatment declines the fruit PO_4^{2-}, $Fe^{2+;3+}$, $Cu^{1+;2+}$ and Mn^{2+} concentrations in both full and half-strength NS. In this case, the $Fe^{2+;3+}$ concentration showed the highest reduction when full-strength Hoagland solution was used. Declines in fruit PO_4^{2-}, SO_4^{2-} concentrations and increases in $Fe^{2+;3+}$ and Mn^{2+} levels were observed in plants watered with half-strength Hoagland solution when compared to those treated with full-strength Hoagland solution, regardless salt treatment.

Irrigation of pepper plants with 15 mM NaCl decreased fruit shape index while half-strength Hoagland solution has not detrimental effect on fruit quality (Table 4). However, juice fructose and glucose concentrations decreased in the saline half-strength Hoagland solution. Similar results were reported by Navarro *et al*., (2002) in pepper plants under saline conditions. These authors indicated that the reduction of sugar concentration in pepper under saline conditions could be due to the increase in fruit respiration. In addition, a high respiration rate in pepper fruit was observed when the ionic strength of the NS was increased (Tadesse *et al*., 1999).

In conclusion, the fruit yield of Orlando pepper plants was reduced by the salt treatment due to a reduction in fruit size rather than a decrease in the number of fruits. However, saline-treated pepper plants irrigated with the half-strength Hoagland solution and with three stems showed the highest fruit yield over the rest of the treatments assayed in salinized plants, mainly due to an increase in the number of fruits per plant. In adittion, using half-strength Hoagland solution resulted in a higher mean fruit weight in plants trained with three stems. In that respect, similar results were obtained when non-prunnig techniques were applied in pepper plants where production of extra-large fruits was higher (Jovicich *et al*., 2004). Under non-saline conditions, this treatment also showed the highest fruit yield. The BER incidence increased by increasing the EC in the NS but decreased using the half-strength Hoagland solution at high irrigation frequency and three-stem training system. The fruit mineral concentration and the fruit quality parameters shape index and juice fructose and sucrose concentration were also decreased by the salinity. Half-strength Hoagland solution can also be employed from the fruit quality point of view, since having little or not detrimental effect on fruit mineral concentration and physico-chemical properties.

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