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# Effect of Nutrient Solution and Pruning on Plant Growth, Yield, and Fruit Quality of Hot Pepper Grown in an NFT System

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## ABSTRACT

**In order to compare the effect of three nutrient solution replacement methods in an NFT system and pruning on hot pepper, a factorial experiment was conducted. Factors included nutrient solution replacement method (complete nutrient replacement, partial nutrient replacement according to EC, and partial nutrient replacement according to plant requirements) and pruning (pruning and non-pruning). Results showed that the highest vegetative growth was recorded in plants fed by complete replacement of nutrient solution, while plant fed based on EC showed the lowest vegetative growth and nutrients concentration. Leaf Chlorophyll a (Chl a) and Total Chlorophyll (TChl) decreased in plants fed according to EC control and plant requirements compared to complete replacement of nutrient solution. All these traits were higher in non-pruned plants than in pruned plants. Fruit yield decreased in plants fed based on nutrient solution EC and plant requirements, and pruning treatment decreased these traits, but the highest single fruit weight belonged to pruned plants fed based on plant requirements. The highest fruit carotenoid content, Total Soluble Solids (TSS), and vitamin C were recorded in plants fed according to nutrient solution EC, and these traits were higher in the pruned plants compared to non-pruned ones. The results also showed that pruning caused a reduction in plant growth and fruit number, therefore, it is not recommended for hot pepper cv. Sentela.**

**Keywords:** *Capsicum annuum* L., cv. Sentela, Nutrient solution replacement, Vegetative growth.

## INTRODUCTION

Production of hot pepper (*Capsicum annuum* L.) has attracted the attention of many consumers and producers due to the high nutritional value provided by vitamins, particularly provitamins A, B, C and nutrients (Ca, P, K, and Fe) (Malik *et al*., 2011). According to FAO (2014), the world production of hot pepper has risen as a consequence of the yield increase per surface area. Production of this crop under a controlled environment is one of the strategic management methods to increase yield per area (Maboko *et al*., 2012). The use of hydroponic systems has been widely developed in horticulture for the production of fruits and vegetables (Niu *et al*., 2015). Managing plant nutrition is one of the most important stages of controlling hydroponic systems that play a key role in plant growth, physiological characteristics, and fruit quality and quantity (Wortman, 2015). Recycle and reuse of nutrient solutions of

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closed hydroponic systems can reduce environmental problems and economic costs (Marschner and Rengel, 2012). Recycle and reuse of nutrient solution not only prevent groundwater pollution but also decrease water consumption during the growing season (Marschner and Rengel, 2012). Therefore, in order to supply nutrients for increasing plant growth and yield in hydroponic systems, some factors such as elements concentration in nutrient solution, nutrient uptake, and plant growth stage should be considered (Marschner and Rengel, 2012). In this regard, some vegetable producers analyze nutrient concentration, pH, and Electrical Conductivity (EC) of nutrient solutions with sensors. However, the use of sensors has decreased due to high costs and disruptions in operation (Bar-Yosef, 2008.). Adjusting the EC of nutrient solution is one of the nutrient management methods under hydroponic conditions. In this method, nutrients absorbed by the plant from nutrient solution is replaced by adding nutrients and the EC of the solution must be kept constant (Lycoskoufis *et al*., 2005). In 'friariello' pepper (Amalfitano *et al*., 2017), plant growth and production decreased at 3.8 $dS.m^{-1}$ or 4.1 $dS.m^{-1}$ in winter-summer or spring-autumn crop cycle, respectively. Plant nutrient requirements change at different plant growth stages. In general, it is higher at the reproduction and fruit set stage (Pedrosa *et al*., 2011). Therefore, nutrients concentration should be modified at the end of the growth stage and the addition of some elements like Ca, N, and P are required (Bar-Yosef, 2008). Schwartz *et al*. (2001) reported that growth and yield of tomato plants were affected by elements concentration in nutrient solution, and based on other authors' findings (Ercolano *et al*., 2015), even by the elemental composition. Elements concentration in nutrient solution affected chlorophyll and photosynthesis parameters by changing ion balance (Pantanella *et al*., 2012). The effect of nutrients concentration on the fruit quality of pepper (Eggink *et al*., 2012) was also reported. Therefore, determination of the suitable nutrient solution and mineral concentration has an important role in yield quantity and quality.

Plant training represents a crucial choice within the crop system (Caruso *et al*., 2009) and, in this respect, pruning plays a major role in enhancing the growth and development of greenhouse crops (Jovicich *et al*., 1999). Leaf area of pepper plants was higher in the single-branched plant compared to that in double and four-branched plants under greenhouse condition (Seifi *et al*., 2012). Several studies emphasized the positive role of pruning on greenhouse crops. For example, the leaf size of the pruned cucumber plant was higher than those of unpruned plants (Hao *et al*., 2010). Also, fruit size and fruit quality of sweet pepper increased by shoot pruning (Jovicich *et al*., 1999).

There is little information on the effects of different methods of supplementary nutrient solution and stem pruning on hot pepper under hydroponic systems. The aims of this study were: (i) To evaluate response of hot pepper to nutrient solution replacement methods (complete replacement, partial replacement based on EC control, and partial replacement according to plant requirements) and pruning (pruning and non-pruning), and (ii) To introduce the best nutrient solution based on plant growth, fruit yield, and fruit quality.

## MATERIALS AND METHODS

This experiment was conducted in 2016 at the experimental greenhouse of Vali-e-Asr University of Rafsanjan, Iran. A factorial experiment based on a completely randomized design with 3 replicates (3 plants at each replicate) was conducted. Two factors were applied: nutrient solution replacement method (complete replacement, partial replacement according to EC, and partial replacement according to plant requirements) and pruning (pruning and non-pruning). Seeds of hot pepper cv. Centella were sown in multicell trays containing coco peat and perlite (1:1 V: V ratio), which were kept in a greenhouse with the relative humidity of 55±3%, temperature of 25±3/18±3ºC (day/night), and a 13/11 hour photoperiod. Then, 21-day-old seedlings were transferred to three NFT systems with two polyethylene gullies (the size was 200 cm length, 20 cm width, and 12 cm height). Every two gullies were connected to a vertical gully that had a channel for transferring nutrient solution to the reservoir tank (50 L). The nutrient solution was pumped from the reservoir tank to the end of polyethylene gully by a submerged pump. This solution returned to the reservoir by gravity-dependent flow. Gully inclination was 1% and the flow rate was 2.4 L $min^{-1}$. After transplanting, seedlings were irrigated by a modified Hoagland's nutrient solution containing: 5 mM $KNO_3$, 5 mM $Ca(NO_3)_2$, 2 mM $MgSO_4$, 1 mM $KH_2PO_4$, 7 µM $MnCl_2$, 0.7 µM $ZnSO_4$, 0.8 µM $CuSO_4$, 0.8 µM $Na_2MoO_4$, 25 µM Fe-EDDHA, and 2 µM $H_3BO_3$. Nutrient solution (pH 6.5±0.1, EC 2.3) was renewed every week. Deionized water was used for nutrient preparation. One month after transplanting (seedling containing two lateral shoots) of hot pepper, nutrient solutions were replaced by three different methods (complete replacement, partial replacement based on EC control, and partial replacement according to plant requirements) for three months. Under complete nutrient solution replacement treatment, nutrient solution was replaced every week. Under partial replacement according to EC, nutrient solution EC was adjusted at 2.3 dS $m^{-1}$ by adding predetermined amounts of potassium sulfate, calcium nitrate, magnesium sulfate, potassium dihydrogen phosphate every 48 hours. Microelements were applied into the nutrient solution every ten days, while under treatment of partial replacement according to plant requirements, the concentration of potassium nitrate was used as Hoaglands' solutions but the concentrations of calcium nitrate, magnesium sulfate, potassium dihydrogen phosphate concentration in nutrient solution were decreased to half strength.

The pruning treatment was applied 40 days after transplanting. In order to do pruning treatment, after the formation of two lateral shoots, new lateral shoots were cut. Pruning treatment continued every week for three times. Sampling for all parameters was done at the end of the experiment. In order to measure leaf and fruit Total Soluble Carbohydrate (TSC), leaf and fruit pigments, fruit color indices, vitamin C and nutrient elements, three plants were chosen per treatment and three samples were selected per plant. Total water consumption was determined with the summing of water amounts added into the three systems, separately. In the treatment of the complete replacing method, the weekly discarded nutrient solution was also summed with replaced water during the entire growing period.

At the end of the experiment, plants were collected and partitioned in root and shoot, and oven-dried (48 houra at 72ºC) to determine Root Dry Weight (RDW) and Shoot Dry Weight (SDW). Leaf area was measured using a leaf area meter (CI-202, Avenue Camas, USA) before drying. The number of leaves and lateral shoots were counted before harvesting. The average number of flowers per plant was counted at the end of the experimental period. The number of fruits per three plants was counted and then the average number of three plants was calculated as the number of fruits per plant during the experiment. At the end of the experiment, seven fruits were randomly selected from each replication and weighed to determine average fruit weight. Finally, fruit yield per plant was calculated. The Chl a, b and total Chl, and carotenoids concentration expressed as mg $g^{-1}$ FW were measured 110 days after transplanting according to Lichtenthaler (1987) method. One gram of the middle part of a fully expanded leaf and fruit tissue was ground with 10 mL of 80% aqueous acetone in mortar and pestle. After filtering, the absorbance of centrifuged extracts was measured at 470, 646, and 663

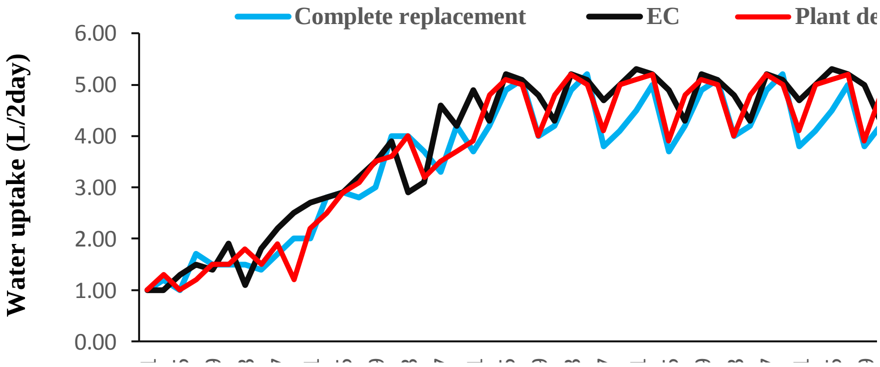


**Figure 1**. Water uptake by hot pepper during growing period in different methods of nutrient solution replacement.

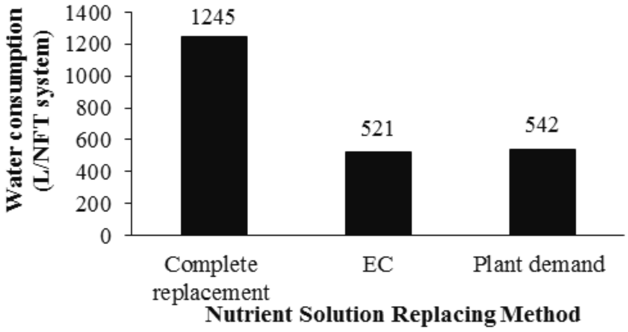


**Figure 2**. Water consumption of NFT systems in different nutrient solutions replacing methods during the growing period of hot pepper.

**Table 1**. Effect of nutrient solution replacing methods and pruning on growth and biometrical indicators of hot pepper in the NFT system.[a]

| Nutrient solution replacing methods | Pruning | RDW (g plant$^{-1}$) | SDW (g plant$^{-1}$) | LA (cm$^2$ plant$^{-1}$) | Plant height (cm) | Leaf number (per plant) | Lateral shoot number (per plant) |
|---|---|---|---|---|---|---|---|
| Complete replacement | Non-pruning | 18±1.2 $^{a}$ | 87±5.8 $^{a}$ | 118±7.8 $^{a}$ | 163±10 $^{a}$ | 241±10 $^{a}$ | 81.3±4.5 $^{a}$ |
| | pruning | 17.7±0.9 $^{ab}$ | 68±3.4 $^{b}$ | 101±5.1 $^{b}$ | 148±7.4 $^{c}$ | 166±9.2 $^{d}$ | 62.0±5.6 $^{c}$ |
| According to EC | Non-pruning | 17.8±1.2 $^{b}$ | 66±8.0 $^{b}$ | 91±1.2 $^{c}$ | 156±9 $^{b}$ | 225±8.6 $^{b}$ | 70.0±2.3 $^{b}$ |
| | pruning | 16.4±1.2 $^{c}$ | 58±4.1 $^{b}$ | 74±5.3 $^{d}$ | 145±10 $^{d}$ | 165±9.2 $^{d}$ | 60.0±4.3 $^{c}$ |
| According to plant requirements | Non-pruning | 17.8±0.8 $^{ab}$ | 88±3.8 $^{a}$ | 97±4.2 $^{bc}$ | 158±6.8 $^{b}$ | 215±9.4 $^{c}$ | 72.3±3.6 $^{b}$ |
| | pruning | 16.9±0.6 $^{bc}$ | 65±2.2 $^{b}$ | 93±3.2 $^{c}$ | 147±5.1 $^{c}$ | 116±4 $^{e}$ | 61.0±3.1 $^{c}$ |

[a] Values are means ±SE of three replicates. Different letters in each column show significant differences at P≤ 0.05 (Duncan).

nm; using a spectrophotometer (model U-2000, Hitachi Instruments, Tokyo, Japan) and pigments concentrations were calculated. To determine fruit vitamin C, 3 mL of fruit juice were diluted and titrated with 20 mL distilled water and 2 mL iodine reagent (2% iodine) in potassium iodide. The titration was continued until the solution changed to gray. One mL iodine regent in potassium iodide equals to 0.88 mg vitamin C. Total Soluble Solids (TSS) was measured by a refractometer (model ATAG, PAL. Japan) and expressed as

**Table 2**. Effect of nutrient solution replacing methods and pruning on the flower number and yield components of hot pepper in the NFT system.[a]

| nutrient solution replacing methods | Pruning | Flower number (plant$^{-1}$) | Fruit number (plant$^{-1}$) | Fruit weight (g) | Yield (kg plant$^{-1}$) |
|---|---|---|---|---|---|
| Complete | Non-pruning | 14.7±0.9 [a] | 65.32±4.35 [a] | 3.12±0.2 [c] | 2.04±0.1 [a] |
| replacement | pruning | 7.33±0.4 [c] | 39.2±1.96 [c] | 2.70±0.13 [cd] | 1.06±0.02 [c] |
| According to EC | Non-pruning | 13±0.5 [ab] | 54.17±2.28 [b] | 3.01±0.5 [c] | 1.63±0.1 [b] |
| | pruning | 7±0.5 [c] | 32±2.28 [d] | 3.84±0.3 [b] | 1.23±0.1 [d] |
| According to plant | Non-pruning | 12±0.5 [b] | 63±2.74 [a] | 2.69±0.1 [d] | 1.7±0.07 [b] |
| requirements | pruning | 6.67±0.2 [c] | 36±1.24 [c] | 4.11±0.1 [a] | 1.35±0.05 [d] |

[a] Values are means ±SE of three replicates. Different letters in each column show significant differences at P≤ 0.05 (Duncan).

°Brix. Hot pepper color (L, a, and b values) was determined with a Minolta Chroma Meter CR-400 (Osaka, Japan). The color measurements were performed using the Hunter Lab System. Color was expressed as changes in Chroma index [= $(a^{*2}+b^{*2})\times0.5$] and L* during growth season. Color values were obtained for 3 fruits per replicate. Three measurements were taken from the equatorial region of each fruit. For determination of nutrient elements, samples of dry leaves were ground and dry-ashed at 550ºC for 4 hours. Ashes were dissolved in 5 mL 2N HCl and then the volume was increased by adding 50 mL distilled water. The concentrations of K were measured by a flame photometer (Jenway, model PFP7, UK). Analyses of Ca, Fe, Zn, Mn, and Cu were carried out with an atomic absorption spectrophotometer (GBC Avanta, Australia) and phosphorus concentration was determined using spectrophotometer according to the method described by Murphy and Riley (1982). Total nitrogen concentration was measured according to the Kjeldahl method and expressed as percent of DW.

A factorial experiment based on a completely randomized design with three replicates was conducted. All data was analyzed by SAS software (9.1), SAS Institute, Cary, NC, USA. When Analysis Of Variance (ANOVA) showed significant effects, the Duncan's multiple range test was applied to compare means at P< 0.05.

## RESULTS

### Water Consumption

Water uptake by plants increased along with plant growth (Figure 1). However, water uptake was not affected by treatments, and it was the same in three nutrient solutions replacing methods, but water consumption decreased by one-third in nutrient solution replacing according to EC and plant requirements compared to complete replacement of nutrient solution (Figure 2).

### Plant Growth

According to the results, the highest values of RDW, SDW, LA, plant height, leaf number, and lateral shoot were recorded in plants fed by the method of complete replacement of nutrient solution (Table 1). The results also showed that, except for RDW, leaf number and lateral shoot number, LA (non-pruning) and SDW (pruning), plant fed according to plant requirements had higher vegetative growth in comparison to EC regulation method. Regardless of the nutrient solution replacement method, pruning significantly decreased plant growth. The reduction of RDW, SDW, LA, plant height, leaf, and lateral shoot number of the pruned plants was about 5, 21, 12, 7.7, 34, and 18% compared to the





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non-pruned plant, respectively (Table 1). As shown in Table 1, vegetative growth parameters (except RDW) of the pruned plants that were fed by complete nutrient solution replacement decreased more compared to pruned plants in the two other methods of nutrient solution replacement (Table 1).

## Flower Number, Fruit Number, and Fruit Yield

As shown in Table 3, pruned plants had lower flower numbers compared to non-pruned plants under all nutrient solution replacing methods. The highest and lowest reduction of flower number was observed in complete nutrient solution replacement and replacing according to plant requirements, about 50 and 44%, respectively (Table 2). The maximum fruit number per plant was recorded in non-pruned plants that were fed by the method of complete replacing solution. However, no significant differences were observed between non-pruned plants in which nutrient solution was replaced completely or according to EC of nutrient solutions. The fruit number per plant was also decreased by pruning. Maximum and minimum reduction of fruit number was recorded in pruned plants that were fed according to plant requirements and the complete replacing method by about 42 and 36%, respectively (Table 2). In the complete replacing method, fruit weight was not affected by pruning, but it significantly increased fruit weight of plants fed according to EC and plant requirements. As shown in Table 3, the maximum and minimum fruit weights were recorded in pruned and non-pruned plants fed according to plant requirements. Fruit yield significantly decreased by pruning. The highest and the lowest reduction of fruit yield were recorded in plants treated by complete nutrient solution replacement and those fed according to plant requirements by about 48 and 20%, respectively (Table 2).

## Leaf and Fruit Pigments and Fruit Color Indices

The highest leaf Chl a concentration was observed in pruned plants fed by the completely replaced solution. Pruning treatment significantly decreased leaf Chl a in plant fed by completely replaced solution, while pruning had no significant effect on leaf Chl a content in plants fed according to nutrient solution EC and plant requirements (Table 3). The highest leaf TChl was recorded in non-pruned plants fed by the completely replaced solution. Leaf TChl concentration in plants fed according to EC was lower by about 20 and 8% compared to plant fed by the completely replaced and according to the nutrient solution EC, respectively (Table 3). Fruit carotenoid increased in pruned plants by about 4, 15, and 13% in the completely replaced solution, and solutions replaced according to EC and plant requirements, respectively. The results also showed that plants fed according to the nutrient solution EC showed the highest fruit carotenoid concentration compared to the others (Table 4). Fruit L* index decreased in pruned plants fed with the completely replaced solutions by about 38%, while pruning had no effects on fruit L* index in plants fed according to nutrient solution EC and plant requirements (Table 5). The highest Chroma index was recorded in non-pruned plants that were fed by the completely replaced solution. Fruit Chroma index was decreased in pruned plants that were fed by completely replaced solution and according to nutrient solution EC while it was not affected in plants fed according to plant requirements (Table 5).

## Total Soluble Solids (TSS), Vitamin C, and Fruit Firmness

As results showed, pruning significantly decreased TSS value by about 8, 13, and 7% in plants fed with the completely replaced solution, according to EC and plant requirements (Table 5). The maximum vitamin C in fruit was recorded in plants fed according to EC and the minimum vitamin C





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**Table 3**. Effect of nutrient solution replacing methods and pruning on leaf and fruit chlorophyll and carotenoids concentrations of hot pepper plants in the NFT system.[a]

| | | Leaf | | | | Fruit | | | |
|---|---|---|---|---|---|---|---|---|---|
| Nutrient solution replacing method | Pruning | Chl a | Chl b | TChl | Carotenoid (mg g$^{-1}$ FW) | Chla | Chl b | TChl | Carotenoid |
| Complete replacement | Non-pruning | 2.8±0.2 a | 0.27±5.8 a | 3.09±0.2 a | 0.2±0.01 a | 0.75±0.03 a | 0.12±0.001 a | 0.87±0.03 a | 1.40±0.1 d |
| | pruning | 2.14±0.1 b | 0.25±3.4 a | 2.37±0.10 ab | 0.18±0.02 a | 0.74±0.02 a | 0.11±0.004 a | 0.85±0.02 a | 1.46±0.1 c |
| According to EC | Non-pruning | 1.93±0.1 c | 026±8.0 a | 2.2±0.1 b | 0.18±0.01 a | 0.74±0.02 a | 0.12±0.002 a | 0.86±0.02 a | 1.59±0.1 b |
| | pruning | 1.92±0.15 c | 0.24±4.1 a | 2.16±0.15 c | 0.2±0.02 a | 0.74±0.03 a | 0.12±0.001 a | 0.86±0.03 a | 1.8±0.1 a |
| According to Plant requirements | Non-pruning | 2.13±0.10 b | 0.285±3.8 a | 2.42±0.10 ab | 0.19±0.02 a | 0.76±0.02 a | 0.12±0.001 a | 0.88±0.02 a | 1.33±0.06d |
| | pruning | 2.07±0.08 bc | 0.275±2.2 a | 2.33±0.08 bc | 0.2±0.01 a | 0.74±0.03 a | 0.11±0.001 a | 0.85±0.03 a | 1.5±0.04c |

[a] Values are means ±SE of three replicates. Different letters in each column show significant differences at P≤ 0.05 (Duncan).

**Table 4**. Effect of nutrient solution replacing methods and pruning on color indices, Total Soluble Solids (TSS), vitamin C and firmness of hot pepper fruit in NFT system.[a]

| Nutrient solution replacing method | Pruning | L* | Hue | Chroma | TSS (°Brix) | Vitamin C (mg Asc acid 100 mg$^{-1}$ fruit juice) | Fruit firmness (Kg F) |
|---|---|---|---|---|---|---|---|
| Complete replacement | Non-pruning | 42.7±2.8 a | 177±5.8a | 7.83±0.52a | 3.22±0.3d | 2.94±0.2 d | 2.14±0.2d |
| | pruning | 26.3±4.0 bc | 176±3.4a | 6.29±0.5 b | 2.96±0.4e | 3.27±0.5 c | 2.46±0.6c |
| According to EC | Non-pruning | 22.7±4.2 cd | 179±8.0a | 5.12±0.4 c | 3.92±0.2a | 3.41±0.4 b | 3.21±0.4a |
| | pruning | 18.7±1.3 d | 177±4.1a | 5.01±0.4 d | 3.41±0.3c | 3.6±0.3 a | 3.1±0.2 a |
| According to Plant requirements | Non-pruning | 27.7±1.2 bc | 179±3.8a | 6.03±0.3 b | 3.63±0.8b | 3.34±0.2 bc | 2.55±0.1c |
| | pruning | 28.3±0.6b | 178±2.2a | 5.92±0.2 bc | 3.39±0.3c | 3.43±0.1 b | 2.67±0.1b |

[a] Values are means ±SE of three replicates. Different letters in each column show significant differences at P≤0.05 (Duncan).

**Table 5**. Effect of nutrient solution replacing methods and pruning on nutrient elements of hot pepper in the NFT system.[a]

| Nutrient solution replacing method | Pruning | N | K | Ca | Fe | Mn |
|---|---|---|---|---|---|---|
| | | (% DW) | | | (mg $kg^{-1}$ DW) | |
| Complete replacement | Non-pruning | 5.9±0.4 [a] | 3.6±0.2 [c] | 1.4±0.1 [a] | 151±10.1 [a] | 98.8±6.6 [a] |
| | pruning | 5.2±0.3 [b] | 3.5±0.2 [cd] | 1.4±0.01 [a] | 140.4±1.8 [bc] | 89.2±1.8 [b] |
| According to EC | Non-pruning | 3.9±0.1 [c] | 3.5±0.1 [d] | 1.2±0.02 [bc] | 136.8±3 [c] | 84.4±3 [c] |
| | pruning | 3.2±0.2 [d] | 3.2±0.2 [e] | 1.1±0.1 [c] | 132±9.4 [e] | 65.1±4.6 [d] |
| According to plant requirements | Non-pruning | 5.5±0.2 [b] | 4±0.2 [a] | 1.2±0.1 [b] | 141.6±6.2 [b] | 84.4±3.7 [c] |
| | pruning | 4.4±0.2 [c] | 3.8±0.1 [b] | 1.1±0.03 [bc] | 134.4±4.6 [d] | 81.9±2.8 [c] |

[a] Values are means±SE of three replicates. Different letters in each column show significant differences at P≤ 0.05 (Duncan

was recorded in plants fed with the completely replaced solution. Vitamin C was not affected by pruning, except for plants fed according to plant requirements in which pruning increased the amount of vitamin C in fruit. The increase of vitamin C in fruit was about 11 and 6% in plants fed by completely replaced solution and according to EC, respectively (Table 5).

The maximum fruit firmness was recorded in plants fed according to nutrient solution EC, and the minimum fruit firmness was recorded in plants fed with the completely replaced solution. Fruit firmness was not affected by pruning, except for plants fed according to EC in which pruning increased fruit firmness compared to the control plants. The increase of fruit firmness in the pruned plants was about 14 and 5% in plants fed by completely replaced solution and according to plant requirements, respectively (Table 5).

### Nutrient Elements

The maximum N, Ca, Fe, and Mn concentrations were recorded in non-pruned plants that were fed with complete replacement of nutrient solution, and the minimum concentrations of these elements were recorded in plants fed according to EC (Table5). The maximum leaf K concentration was also recorded in plants fed according to plant requirements (Table 5).

## DISCUSSION

The results of the present study showed that different replacing methods of the nutrient solution had a significant effect on vegetative growth parameters of the hot pepper plants. The highest and the lowest vegetative growth were observed in plants fed with the completely replaced solution and replaced according to EC of nutrient solution, respectively. Reduction in vegetative traits under nutrient solution replacement according to EC may be due to high nutrient elements (especially Ca, Mg, and S) concentration around the root that changed the nutrient imbalance (Degl'Innocenti *et al*., 2009). Proper nutrient balance under complete replacement method compared to other treatments caused the increase of water and nutrient uptake, and accordingly of plant growth (Zhang *et al*., 2006). Zhu *et al*. (2007) reported that disturbed mineral balance of nutrient solution was one of the reasons for plant growth reduction. The effect of different nutrient solutions on plant growth was previously reported on tomato (Schwartz *et al.,* 2001) and artichoke and cardoon (Rouphael *et al*., 2012), which are consistent with our results. In this study, pepper plants fed with completely replaced solution had higher growth compared to plants fed according to plant requirements. Determination of requirements of pepper plants to different concentrations of nutrient elements was based on previous studies; therefore, reduction of growth in plants fed according to plant requirements in comparison with the complete replacement method may be due to the variation in responses of different cultivars to changes in the nutrient solution. Since the optimum pH range of the nutrient solution for pepper growth is between 5 and 6 (Navarro *et al*., 2002), decreasing pepper growth under nutrient replacing according to EC and plant requirements could be due to the high pHs of these nutrient solutions that were about 6.55 and 6.68, respectively. Therefore, relative pH increases in the nutrient solutions decreased plant growth by affecting nutrient absorption *(*Valdez Aquilar and Reed, 2007*).*

Pepper plants have sympodial patterns of growth. It means that flower bud formations inhibit apical meristems activity and then lateral buds act as apical meristems (Cohen *et al.,* 2014). In previous research, leaves formed on the lateral shoot had an important role in photosynthesis activity (Cohen *et al.,* 2014). Therefore, eliminating the lateral shoot of pepper plants reduced plant growth by excluding photosynthetic leaves (Elitzur *et al.,* 2009). On the other hand, removing the new lateral shoot leads to the imbalance of hormones and carbohydrate in plants with a sympodial pattern (Pnueli *et al*., 2001). These findings are consistent with our results that pruning reduced the plant growth significantly. However, the correct time of pruning in sympodial plants could improve plant growth. Removing new lateral shoot decreased plant growth while removing old lateral shoot or leaves improved plant growth (Jovicich *et al.,* 1999). Increasing plant growth by removing old leaves may be due to the removal of ethylene sources produced by old leaves (Jovicich *et al.,* 1999).

The results of the present study showed that fruit yield, flower, and fruit number decreased in plants fed according to EC of the nutrient solution compared to complete replacement method and plant requirements. These findings are in agreement with the results reported by Fandi *et al*. (2010) on tomato, Andriolo *et al*. (2009) on strawberry, and Giuffrida and Leonardi (2012) on pepper, showing imbalance nutrient solution decreased fruit yield. Decreasing fruit yield in the imbalanced nutrient solutions may be due to the antagonistic effect of some elements on the other nutrient elements. On the other hand, the observed reduction in root growth could decrease the absorption of water and nutrients and, consequently, fruit and flower numbers under imbalance plant nutrition (Wu, 2006). Pepper plants grown in the completely replaced solution had higher Zn concentration than plants grown in the nutrient solution replaced according to EC and plant requirements, which can play an important role in fruit set and reduction of flower abscission. Kaska (1989) reported that citrus genotypes with higher leaf Zn concentration had fewer flower buds abscission. Our results also showed that pruning decreased fruit yield, and fruit and flower number but increased average fruit weight. Since flower formation in pepper plants occurred at the end of apical meristems, removing lateral shoot decreased flower primordia and flower number and fruit number (Elitzur *et al.,* 2009). Increasing fruit weight in pruned plants may be due to decreased fruit number, as more water and carbohydrate increase carbohydrate availability to remaining fruits and results in an increase in weight and size of fruits (Jovicich *et al.,* 1999). Previous reports showed that removing the lateral shoot of pepper plants decreased fruit yield and fruit number per plant (Jovicich *et al.,* 1999), which are in agreement with our results. However, Maboko *et al.* (2012)





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reported that removing the old lateral shoot of pepper plants increased the number of fruit and yield.

The results of the present study showed that the highest Chl a and TChl concentrations were recorded in plants fed by the nutrient solution according to the complete replacement method, but nutrient replacement according to EC caused a marked reduction in them. Lower concentration of N, Fe, and Mn in the plants fed according to EC could be an important part of the reason for Chls reductions in this treatment. Little information has been reported regarding the effect of pruning on chlorophyll concentration. A study on eggplant showed that shoot pruning had no significant effect on photosynthesis pigments (Ambroszczyk *et al.*, 2008). However, our results indicated that pruned plants had lower Chl a and TChl concentration in leaves.

Pepper fruit is a rich source of natural pigments, antioxidants, and vitamin C (Jovicich *et al*., 1999). Several factors, such as light and mineral nutrition, may affect the fruit quality under greenhouse conditions (Wortman, 2015). During fruit growth, some biochemical changes such as increasing carotenoids, vitamin C and TSS, and decreasing Chl may occur (Wu, 2006). Therefore, changing the concentration of nutrient elements can control the fruit quality in hydroponic systems (Wortman, 2015). In general, fruit quality indices can be classified according to their appearance (size, weight, color) and aroma (Jovicich *et al*., 1999). The results of the present study showed that fruit quality characteristics like fruit firmness, carotenoid, color indices, vitamin C, and TSS were affected by nutrient solutions. The highest carotenoids, TSS, vitamin C concentration, and fruit firmness were recorded in plants fed according to EC of nutrient solution, while color indices decreased in this condition. Similar responses have been reported in tomato (Wu, 2006) and tomato and pepper (Wortman, 2015) under high EC of the nutrient solutions induced by increasing mineral elements concentration. Rubio *et al.* (2010) reported that organic acid content of pepper fruit was enhanced by increasing K and Ca concentration in the nutrient solution. Tomato plants fed with high EC of the nutrient solution had more lycopene and vitamin C in fruits than plants fed with standard nutrient solution (Wu, 2006). On the other hand, decreasing color indices in pepper fruit that were fed according to EC of nutrient solution may be due to the change in carotenoids concentration. High firmness of pepper fruits may be due to a decrease in the water content of pepper fruit. Pallavi *et al*. (2015) reported that fruit water content had a significant effect on fruit texture. Fruits that had more water content had a softer texture. Seifi *et al*. (2012) reported that increasing light intensity by removing the lateral shoots of pepper plants increased fruit quality by the accumulation of vitamin C and TSS. While pruning had no significant effect on total acid, lycopene, and Chl content of tomato fruits (Candian *et al.*, 2015). Jovicich *et al.* (1999) also reported that vitamin C content of pepper fruit was increased in pruned plants. Removing the lateral shoots of pepper plants in high-density conditions increased the fruit firmness in comparison with unpruned plants (Maboko *et al*., 2012).

The results of the present study showed that leaf nutrient elements of hot pepper plant decreased in plants fed according to EC of the nutrient solution. This may be due to: (i) Decreasing water potential, (ii) Disruption of ion balance, and (iii) Decreasing root growth. On the other hand, leaf Ca concentration was higher under complete nutrient solution replacement compared to other treatments. High Ca concentration in this condition may be due to high root growth. This is in agreement with the results of Albornoz *et al*. (2014) who reported high EC of the nutrient solution decreased K and Ca concentration of lettuce plants. High leaf K concentration under the nutrition treatment according to plant requirements could be due to the high level of potassium in the nutrient solution.





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## CONCLUSIONS

The results showed that the highest vegetative and reproductive growth and nutrient elements concentrations were recorded in plants fed with the method of complete nutrient solution replacement, while plants fed based on nutrient solutions' EC showed the lowest vegetative growth and nutrients concentrations. The highest fruit carotenoid concentration, TSS, and vitamin C concentration were observed in plants fed according to EC of nutrient solutions, and these traits were higher in pruned plants compared to non-pruned plants. Compared to the method of complete replacement of nutrient solution, plant growth and fruits number in the other two systems decreased; but regarding the reduction of nutrient solution consumption and increasing fruit quality, more study is necessary about the latter two methods. The results also showed that pruning caused a decrease in plant growth and fruit number, therefore, it is not recommended for hot pepper cv. Sentela.

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# اثر محلول غذایی و هرس بر رشد، عملکرد و کیفیت میوه فلفل تند در سیستم NFT

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## چکیده

برای مقایسه اثر سه روش جایگزینی محلول غذایی در سیستم NFT و هرس بر فلفل، آزمایشی به-صورت فاکتوریل اجرا شد. فاکتورها شامل روش‌های جایگزینی محلول غذایی (جایگزینی کامل محلول غذایی، جایگزینی محلول جذب شده بر اساس EC و جایگزینی محلول جذب شده بر اساس نیاز گیاه) و هرس (گیاه هرس شده و گیاه هرس نشده) بود. نتایج نشان داد که بیشترین رشد رویشی در گیاهانی مشاهده شد که محلول غذایی آنها به‌طور کامل تعویض می‌شد در حالی که گیاهان تغذیه شده بر اساس EC کمترین رشد رویشی و غلظت عناصر غذایی را دارا بودند. کلروفیل a و کلروفیل کل در گیاهان تغذیه‌شده بر اساس EC و نیاز گیاه در مقایسه با تیمار جایگزینی کامل محلول غذایی کاهش یافت. همه این صفات در گیاهان هرس نشده بیشتر از گیاهان هرس شده بود. محصول میوه در گیاهان تغذیه شده بر اساس EC محلول غذایی و نیاز گیاه کاهش یافت و تیمار هرس نیز این صفت را کاهش داد ولی بیشترین وزن تک میوه در گیاهان هرس شده‌ای مشاهده شد که بر اساس نیاز گیاه تغذیه شده بودند. بیشترین غلظت کارتنوئید، مواد جامد محلول کل (TSS) و ویتامین C در گیاهان تغذیه شده بر اساس EC محلول غذایی مشاهده شد و این صفات در گیاهان هرس شده بالاتر از گیاهان هرس نشده

بود. نتایج همچنین نشان داد که هرس باعث کاهش رشد و تعداد میوه در گیاه شد و بنابراین برای فلفل تند رقم سنتلا هرس پیشنهاد نمی‌شود.



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