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ROOT GROWTH CHARACTERISTICS OF KHATOUNI MELON SEEDLINGS AS AFFECTED BY POTASSIUM NUTRITION

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ABSTRACT

Khatouni melons are a major horticultural crop that is produced mainly in semi arid and arid regions of Iran. The plant root characteristics can significantly affect many growth traits, including water and nutrients uptake under such dry conditions. On the other hand, nutrient elements concentration and their ratios can strongly affect the root morphophysiological and structure. In this study, the growth and root system characteristics of Khatouni melon was evaluated under various potassium (K) levels of nutrient solution. A rhizobox system with sand-hydroponic culture was applied. Hoagland formula was used for nutrient solution preparation, and different potassium levels of 0, 59, 118, 176 and 235 mg L^{-1} K of nutrient solution were applied to plants, while other nutrients were kept relatively unchanged. The results showed that the highest shoot fresh weight, leaf area and SPAD value were at 235 or 176 mg L^{-1} K, whereas the root characteristics were affected by K treatments in different patterns. The highest root fresh weight was in plants treated with 118 mg L^{-1} K, whereas root dry weight was significantly lower in treatment without K nutrition than other K levels of nutrient solution. Plant root diameter was thickest at 176 mg L^{-1} K and it was longest at 118 mg L^{-1} K, whereas the shortest roots were at 235 mg L^{-1} K of nutrient solution. Root area was the highest at 118, 176 and 235 mg L^{-1} K of nutrient solution. Root nutrient concentration of N, K, P, Ca and Fe was the highest at 118 or 176 mg L^{-1} K; however, the lowest amount of root Mg and Fe was in plants treated with 235 mg L^{-1} K. For other traits of root and shoot growth, the lowest records were in treatment without K nutrition. The results indicate that shoot or root growth characteristics of Khatouni melon can be improved by moderate to high, or moderate potassium levels.

Key words: Cucurbitaceae, fertilization, nutrient uptake, plant root, seedling, vegetable

INTRODUCTION

Fertilization management in agriculture, particularly in hot arid climates, is important due to economic and environmental issues. Mismanagement of nutritional requirements of agricultural crops during last decades resulted in serious life and environmental challenges [Souri 2016, Zivdar et al. 2016]. Both chemical and organic fertilizers, in their applications, can significantly contribute to the soil and environmental pollution.

Nutrients availability and the nutrients ratios are important factors effective on growth and yield production of agricultural crops [Marschner 2011]. Potassium is a major nutrient element that is required by plants in relatively high amounts [Römheld and Kirkby 2010, Marschner 2011, Nurzyńska-Wierdak et al. 2012]. This is mainly due to the emerging role of K in a number of biotic and abiotic stress situations, including diseases and pests, frost, heat/dro-

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ught, and salinity [Römheld and Kirkby 2010, Zörb et al. 2014]. In addition, K is the major cation in plant cells functioning as an osmolite and in cation-anion balances [Lester et al. 2010, Nurzyńska-Wierdak et al. 2011]. The role of K in plant cell physiology has been well documented during last decades [Cerda et al. 2008, Römheld and Kirkby 2010]. Potassium has vital roles in nutrient uptake and assimilation, N metabolism, photosynthesis, phloem loading and assimilates transport, maintaining membrane potential and cell turgor, activating enzymes, regulating osmotic pressure and stoma movement [Römheld and Kirkby 2010, Marschner 2011, Zörb et al. 2014]. It is also the most abundant cation in cytoplasm and in the vacuole.

It has been shown that potassium is a key nutrient in root growth and development [Jia et al. 2008, Wu et al. 2009]. Large root system is of a vital importance for crops such as Khatouni melons that are grown in arid and semi arid regions (in Iran) with potential water scarcity challenges. General global warming and low precipitation rates during recent decades has faced Iranian agriculture with serious water crises. In many parts of the country, exploitation of underground water is the only choice to supply crops with required irrigation, and on the other hand, high application rates of chemical fertilizers, including urea, potassium and phosphorus, have deteriorated the soil quality in many regions. In many regions under melon cultivation, irrigation water contains high levels of Na, Mg, K, B and Cl that frequently reduce plant growth quality.

During last decades, a very rapid progress was made in elucidating the role of K, particularly in relation to stress signaling by the use of modern molecular biological approaches [Römheld and Kirkby 2010]. Soil nutrients regulate fine-root abundance, morphological and chemical traits, and their association with mycorrhizal fungi in a species-rich lowland tropical forest [De Dorlodot et al. 2007, Wurzburger and Wright 2015]. Therefore, the cultivation management toward a vast and efficient root system with enhanced ability for water and nutrient uptake is highly needed. In addition, the root branching pattern under different levels of specific nutrient minerals is not well documented. The plant requirement of K, particularly in various developmental stages, is also not clear for many crops. The obstacle regarding the role of nutrient elements, particularly potassium, on root system development, in particular at seedling stages, needs to be elucidated. Therefore, in the present study, the role of different potassium levels of nutrient solution on growth and root characteristics of melon seedlings, was evaluated.

MATERIAL AND METHODS

This study was carried out under greenhouse conditions and hydroponic culture system during summer of 2016 at Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran. The seeds of Khatouni melon (*Cucumis melo* var. inodorus subvar. Khatouni) were first disinfected using 1% hypochlorite solution for 30 minutes and then treated with Benomyl fungicide. Rhizoboxes of 50 × 30 × 5 cm (length/width/diameter) dimensions (about 7 L volume), designed specifically for root studies, were used for plant cultivation. Rhizoboxes were filled with fine sand (0.05–0.1 mm diameter) that was completely washed out for cleanness before application. Three seeds were sown in each rhizobox, and after germination, the stronger seedling was kept and two others were immediately removed. Thereafter, melon plants were fed with different potassium levels of nutrient solution. Hoagland formula was used for preparation of nutrient solution with some modifications. Distilled water was used for nutrient solution preparation. The original EC and pH of nutrient solution were 1.8 dS m^{-1} and 6.3, respectively.

Different potassium (K) levels, including 0, 59, 118, 176 and 235 mg L^{-1} of nutrient solution were applied to plants in four replications, in which a rhizobox represented a single replication containing one plant. The 235 mg L^{-1} level was the standard Hoagland nutrient solution concentration of potassium. Different potassium concentrations of nutrient solution were prepared by changing the amounts of KNO_3 and/or KH_2PO_4 and replacement of companion anion(s) with appropriate salts. In 176 mg L^{-1} treatment, 0.75 mL calcium nitrate (1M) was added to solution for compensation of nitrogen. In 118 mg L^{-1} treatment, 1.5 mL calcium nitrate (1M) was added to

compensate nitrogen level. In 59 mg L^{-1} treatment, 2.25 mL calcium nitrate (1M) was added to compensate nitrogen level. In 0 treatment, all potassium salts of Hoagland solution was removed and for compensation of nitrogen and phosphorus, 2.5 mL calcium nitrate (1M) and 1 mL mono ammonium phosphate (1M) was added to solution. Plants were grown for three weeks under potassium treatments. The greenhouse temperature during plant growth period was 30 ±5°C and relative humidity was 70–75% with a light intensity of 250 µmol $m^{-2}s^{-1}$. An amount of 200 ml nutrient solution (differ in K concentration) per rhizobox was applied daily to plants.

The plants were harvested after three weeks of seedling emergence. Leaf SPAD values were recorded by SPAD meter with average of 20–30 reading of different parts of plant leaves per rhizobox. The whole plant leaf area was measured by leaf area meter (Delta-T Devices Ltd, England) and calculated per single leaf. At harvest, the shoots were cut and gently removed from sand particles, washed with distilled water and after that, dried using tissue paper. Shoot and root fresh weight were measured using a precise digital balance. For measuring root dry weight, the root material was placed in an oven at 65°C for 48 h, then dry weight was measured using a digital scale. The overall root length was measured using a precise ruler and for determination of root nutrient element concentrations, various procedures were applied. An amount of 0.2 g dry powder of root tissue was placed in a muffle furnace at 550°C for 6 h for dry combusting. After cooling, the samples were extracted 2 times using 2 ml of 1/3 HNO3 (v/v) and heated to dryness. The ash was dissolved in 2 ml of 1/3 HCl (v/v), and then diluted to 10 ml with hot deionized water, then the amount of nitrogen was measured using Kjeldahl method, potassium using flame photometry, phosphorus using spectrophotometer, and Ca, Mg and Fe were measured using atomic absorption method.

Determination of total root length, root surface and root diameter were carried out using a scanner (Delta-T SCAN Image Analysis). For this purpose, one gram of fresh roots was first treated with purple methyl dye and then scanned using Delta-T SCAN image analysis, and thereafter, the sum of root length was calculated using Root Edge Software. Plant root volume was also determined after root placement in a given water volume and then calculated as cm^3 root volume per plant.

Data were analyzed using the SPSS statistical software package and mean values were compared using Duncan's multiple range tests at 5% level.

RESULTS

The results showed that plant leaf area was largest at 176 and 235 mg L^{-1} K of nutrient solution, followed by 118 mg L^{-1} K treatment (Tab. 1). The smallest leaf area was in plants treated with combination without K nutrition. Shoot fresh weight followed a similar trend, in which the highest plant shoot fresh weight was in plants treated with 176 mg L^{-1} K that showed no significant difference with those plants treated with 235 mg L^{-1} K or 118 mg L^{-1} K of nutrient solution (Tab. 1). Leaf SPAD value was the highest at 235 mg L^{-1} K treatment that showed no significant difference with 176 mg L^{-1} K. The significant lowest plant shoot fresh weight was in plants treated without K nutrition (Tab. 1). The lowest shoot fresh weight, leaf area and leaf SPAD value were in plants receiving treatment without K nutrition.

Determination of root diameter showed that plants treated with 176 mg L^{-1} K had thicker roots than other K treatments, and the thinnest roots were in plants treated with 59 mg L^{-1} K (Tab. 1). Overall root length was the highest when plants received 118 mg L^{-1} K that showed no significant difference to other K levels, except from 235 mg L^{-1} treatment, which showed the shortest root length (Tab. 1). Plant root volume was the highest in treatment with 118 and 59 mg L^{-1} K, followed by 176 and 235 mg L^{-1} K of nutrient solution. The lowest root volume was in plants treated with combination without K nutrition (Fig. 1). Similarly, the highest root fresh weight was obtained from 118 mg L^{-1} K treatment, and the lowest root fresh weight was in treated plants without K nutrition (Fig. 2). There was no difference in root fresh weight among 59, 176 and 235 mg L^{-1} K of nutrient solution. However, the lowest root dry weight was in plants treated with combination without K nutrition and there was no difference among other K treatments (Fig. 2).

Table 1. Effect of potassium nutrition on leaf area, shoot fresh weight, SPAD value, root diameter and overall root length of melon plants

K levels (mg L^{-1})	Leaf area (cm^2)	Shoot FW (g)	SPAD value	Root diameter (mm)	Overall root length (cm)
0	74.8 ±12.6c	32.4 ±5.9c	15.7 ±2.1c	0.48 ±0.015b	52.7 ±4.5a
59	98.9 ±9.9b	41.5 ±4.6b	19 ±2.0b	0.43 ±0.023c	51.8 ±5.7ab
118	109.5 ±10.6ab	49.3 ±8.6ab	21.7 ±2.5b	0.48 ±0.013b	53.3 ±6.6a
176	122.5 ±13.7a	58.4 ±7.1a	25 ±3.6ab	0.53 ±0.055a	45 ±7.0ab
235	121.2 ±14.7a	57.7 ±4.1a	29 ±4.6a	0.46 ±0.01bc	42.6 ±3.5b

Comparison of means was performed at 5% level of Duncan's multiple range test

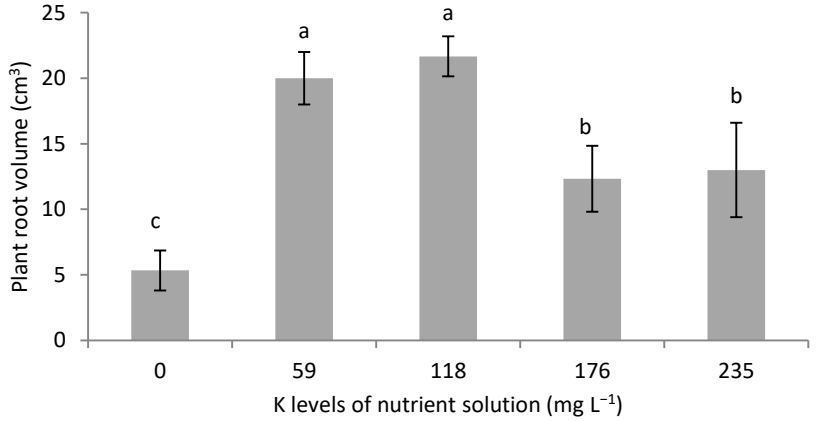

Fig. 1. Root volume of Khatouni melons under different K levels of nutrient solution. Comparison of means was performed at 5% level of Duncan's multiple range test

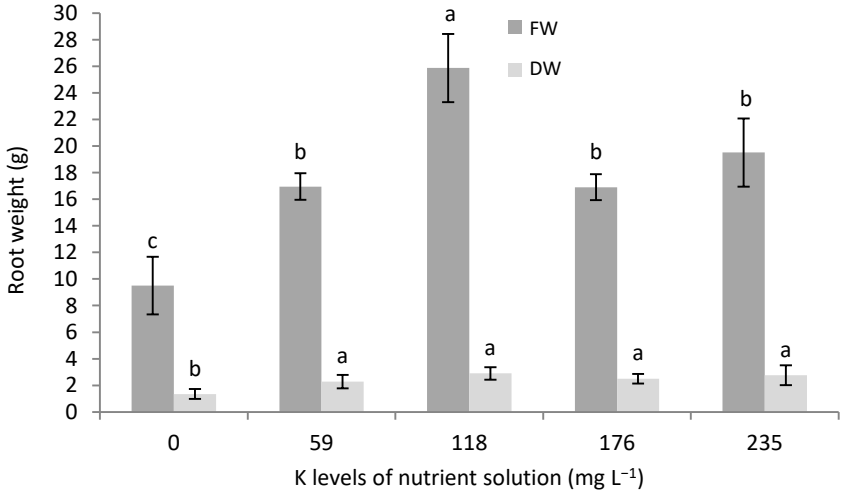

Fig. 2. Root fresh and dry weight of Khatouni melons under different K levels of nutrient solution. Comparison of means was performed at 5% level of Duncan's multiple range test

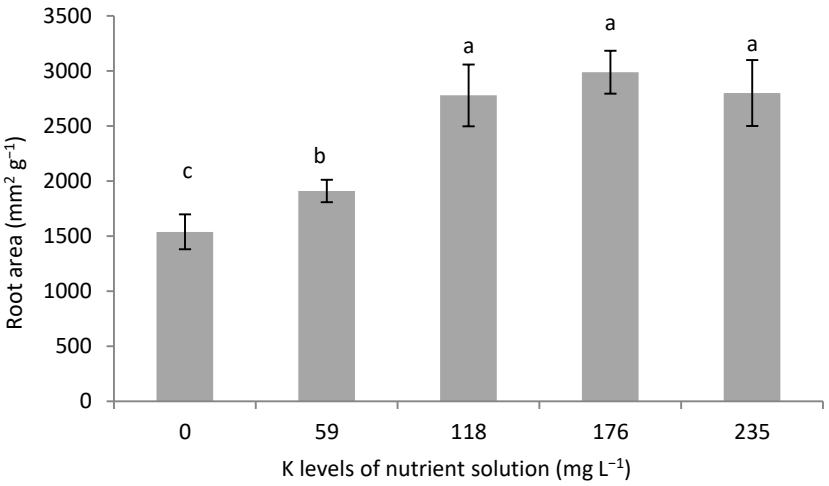

Fig. 3. Root area of Khatouni melons under different K levels of nutrient solution. Comparison of means was performed at 5% level of Duncan's multiple range test

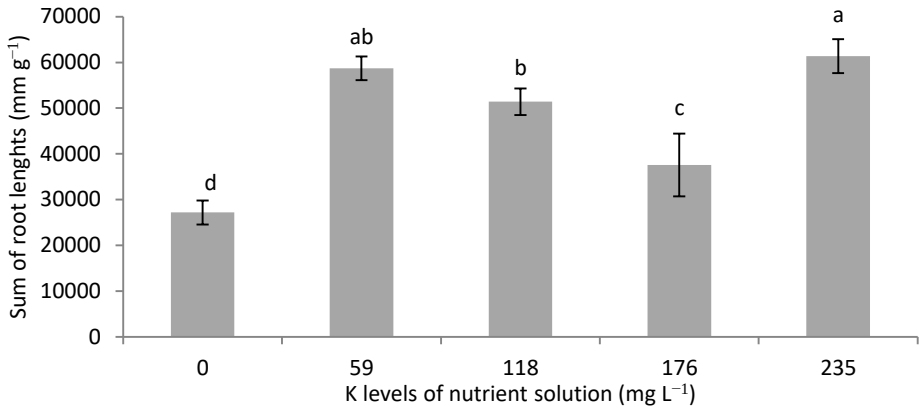

Fig. 4. Sum of root lengths in Khatouni melons under different levels of K of nutrient solution. Comparison of means was performed at 5% level of Duncan's multiple range test

Table 2. Effect of potassium nutrition on chemical composition (nutrient elements) of melon's root

K levels (mg L^{-1})	N con. (% DW)	K con. (% DW)	Ca con. (% DW)	Mg con. (% DW)	P con. (% DW)	Fe con. (mg kg^{-1} DW)
0	0.4 ±0.1c	0.43 ±0.02c	2.24 ±0.43b	0.74 ±0.10a	0.32 ±0.07b	166 ±10ab
59	0.73 ±0.11bc	0.49 ±0.08b	2.85 ±0.26a	0.76 ±0.11a	0.49 ±0.08a	139.1 ±20bc
118	1.45 ±0.4a	0.61 ±0.11a	2.83 ±0.31a	0.69 ±0.10ab	0.53 ±0.10a	181.5 ±23a
176	0.97 ±0.21ab	0.50 ±0.06b	2.79 ±0.31a	0.63 ±0.09ab	0.42 ±0.05ab	122.1 ±26c
235	0.90 ±0.15b	0.50 ±0.03b	2.65 ±0.36ab	0.53 ±0.06b	0.40 ±0.08ab	125.9 ±12c

Comparison of means was performed at 5% level of Duncan's multiple range test

Determination of root area showed that the highest root area (per g root fresh weight) was in plants treated with 118, 176 and 235 mg L^{-1} K of nutrient solution, whereas the lowest root area was in plants treated with combination without K nutrition (Fig. 3). However, the sum of root lengths (per g root fresh weight) was the highest in plants treated with 235 mg L^{-1} K that showed no significant difference from plants treated with 59 mg L^{-1} K (Fig. 4). The lowest sum of root length was in plants that received treatment without K nutrition. Among K treated plants, plants that received 176 mg L^{-1} K showed the lowest sum of root lengths (Fig. 4).

It was found that the highest root nitrogen concentration was determined in plants treated with 118 mg L^{-1} K of nutrient solution, and the lowest amount was in plants received treatment without K nutrition (Tab. 2). Root potassium concentration was the highest at 118 mg L^{-1} K of nutrient solution, whereas the lowest root potassium was in plants receiving treatment without K nutrition (Tab. 2). Root calcium concentration was the lowest in treatment without K nutrition, whereas there was no difference among higher K levels of nutrient solution (Tab. 2). However, regarding root magnesium concentration, the lowest amount was in plants treated with 235 mg L^{-1}, and there was no difference in root Mg concentration among other K levels of nutrient solution (Tab. 2). Root phosphorus concentration was the highest at 118 mg L^{-1} K of nutrient solution; however, it showed no difference with 59 or 176 or 235 mg L^{-1} K of nutrient solution. The lowest root P was in plants received treatment without K nutrition. The highest root Fe status was found in case of plants treated with 118 mg L^{-1} K of nutrient solution that showed no difference with plants receiving treatment without K nutrition (Tab. 2). The lowest root Fe was in plants treated with 176 or 235 m L^{-1} K of nutrient solution.

DISCUSSION

The results of the present study showed that shoot growth parameters of leaf area, shoot fresh weight and leaf SPAD value were the highest at 235 or 176 mg L^{-1} K of nutrient solution. However, the root characteristics, including root fresh and dry weight, root volume and root area were the highest at 118 mg L^{-1} K and root diameter was the highest at 176 mg L^{-1} K of nutrient solution. This indicates that shoot growth needs higher K levels than root growth and generally as we see and look for shoot growth, our fertilization activity may restrict the root growth and root system development. Potassium is a key macronutrient with various metabolic roles in plant cell function, and there are always good plant responses to K application [Römheld and Kirkby 2010, Marschner 2011]. From plant and human health point of view, high potassium concentration in plant tissues is always desired and adequate levels of K can guarantee many quality aspects of crops with maximum beneficial effects [Zörb et al. 2014, Zivdar et al. 2016]. Owing to its fundamental roles in turgor generation, primary metabolism, and long-distance transport, K plays a dominant role in crop resistance to drought, salinity, high light, or cold as well as to pests and pathogens resistance [Römheld and Kirkby 2010, Zörb et al. 2014]. In various studies, it has been shown that application of potassium fertilizers has increased vegetative growth, yield and quality of various crops [Cerda et al. 2008, Lester et al. 2010, Nurzyńska-Wierdak et al. 2011, 2012, Zivdar et al. 2016]; however the effect of K levels on root growth and development was not well studied.

In this study, the effects of K levels on melon root morphophysiological characteristics revealed that medium levels of K in nutrient solution are beneficial, as the highest root fresh weight, root length, root area and root volume were obtained at 118 mg L^{-1} K of nutrient solution. It seems that higher K levels of 176 or particularly 235 mg L^{-1} K of nutrient solution reduced some root growth traits, probably due to very complex mechanisms. Such inhibiting effect of high K fertilization on root growth has also been reported for other crops [Van den Driessche 1992, Jia et al. 2008, Wright et al. 2011]; however, it has been shown that K deficient treatments have inhibited the root length and the formation of lateral roots in cotton [Zhang et al. 2009]. In maize, without K application, the root length, volume and surface area of K-deficiency tolerant genotype was significantly higher than K-deficiency sensitive genotype at different growing stages [Zhao et al. 2016]. In Douglas

Fire, the root growth was more responsive to soil N status than K application [Van den Driessche 1992], and application of N, P or K in relatively fertile soils restricted the root and shoot growth in lowland tropical forest trees [Wright et al. 2011]. Addition of N, P, and K together reduced the fine-root biomass, length, and tissue density, and increased specific root length, whereas root diameter remained unchanged in lowland tropical forest trees [Wurzburger and Wright 2015]. All these studies indicate that despite low levels, K may restrict the root growth; however, high K levels frequently restrict root growth of plants. Similar results were also obtained in the present study.

Genotypic differences in nutrient uptake due to root size and morphology and/or to root physiology, are important determinants of nutrient efficiency [De Dorlodot et al. 2007, Marschner 2011]. Better translocation of K into different organs, greater capacity to maintain cytosolic K concentration within optimal ranges and increased capacity to substitute Na for K are the main mechanisms underlying K utilization efficiency [Rengel and Damon 2008]. Nevertheless, a well developed root system is critical for optimum nutrient uptake, particularly under adverse climatic conditions. The plant root system is highly sensitive to nutrient availability and distribution in the soil profile. Root morphology parameters are involved in root uptake of K, and in potassium translocation to shoots [Jia et al. 2008]. Such effects were also observed in our study with different K levels of nutrient solution. The root growth of six rice genotypes was reduced under low K (5 mg L^{-1}), but moderate K deficiency (10 mg L^{-1}) increased the root length of the efficient genotypes [Jia et al. 2008]; however, short-term removal of K supply (9 days) in rice did not affect the root morphology and biomass ratio of roots to shoots [Wu et al. 2009]. At deficient and moderate K levels, all the efficient rice genotypes developed more fine roots than the inefficient genotypes [Jia et al. 2008]. Our results also indicate that the Khatouni melons are K efficient plants and may not need high potassium fertilization. However, genotypes efficient in K uptake may have a larger surface area of contact between roots and soil, and higher uptake rate at the root–soil interface to maintain larger diffusive gradient towards roots [Rengel and Damon 2008]. Large root system is one of the main factors towards potassium efficiency in cropping systems [Steingrobe and Claassen 2000]. In addition, root elongation and branching besides other above ground mechanisms, enable plants to overcome the water stress in arid regions [Sangakkara et al. 1996].

Plant roots are the primary organs for sensing potassium status of soil, and therefore under low K conditions, roots activate the optimal potassium uptake system to acquire more potassium. Plants constantly sense the changes in their environment; when mineral elements are scarce, they often allocate a greater proportion of their biomass to the root system [Hermans et al. 2006]. In fact, root cells can sense the soil potassium status and initiate a series of physiological reactions [Schachtman and Shin 2007]. These reactions include both biochemical and morphological adaptive changes in root structure [Wang and Wu 2010]. The acclamatory responses are consequence of metabolic changes in the shoot and an adjustment of carbohydrate transport to the root [Hermans et al. 2006]. These responses and related mechanisms are vital for plant survival under dry climate with frequently water shortages. Therefore, with better management of potassium (and other nutrients) fertilization, it is possible to help plants for better adaptation to adverse conditions of dry climates.

CONCLUSION

The results of the present study showed that high K nutrition reduced the root growth characteristics in Khatouni melons, as the highest root growth characteristics were at 118 mg L^{-1} K of nutrient solution. Soil nutrients act as a sensor for root development in a process of plant root sensing induced by nutrient elements concentration and their corresponding ratios. However, mechanisms of external and internal nutrient sensing are not well known. Plant adaptation to changes in the nutrient status of soils is vital for a long-term productivity and growth, particularly under adverse climatic conditions. The plant potential for nutrients and particularly water uptake in dry climates, is governed by the size and structure of root system. In the present study, high K levels of nutrient

solution restricted the root growth, whereas in plants such as Khatouni melons, development of an extensive root system enables plants to overcome water shortages during hot summer growth period with increasingly less available irrigation water.

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