Water Deficit Decreases Gas Exchange Parameters and Marketable Quality of *Rosa hybrida* 'Club-Nika' Irrespective of Training Systems

A. Dolatkhahi[1], M. Shoor[1*], M. Bannayan[2], A.Tehranifar[1], and A. Alizadeh[3]

ABSTRACT

The present study was carried out to investigate biochemical, morphological, and physiological processes involved in the adaptive processes of cut roses grown in arching and high-rack culture systems under water deficit condition. Rose plants 'Club-Nika' were subjected to three water regimes [control (100% of irrigation needs), moderate water stress (75%), and severe water stress (50%)] factorially combined with two training systems defined as arching and high-rack systems. Water deficit significantly reduced morphological and qualitative traits as well as water relations of cut roses. Water deficit significantly reduced Net CO_2 assimilation rate (P_N), transpiration rate (E), and stomatal conductance (g_s), whereas it did not affect Water Use Efficiency (WUEi) and intercellular CO_2 concentration (C_i). Surprisingly, water deficit did not affect chlorophyll content [chl *a*, chl *b* and total chl (*a* + *b*)] and proline accumulation of leaves. Considering the lack of change in intercellular CO_2 concentration, it seems likely that both stomatal closure and metabolic impairment limit photosynthetic CO_2 assimilation under water deficit. Regardless of irrigation regimes, rose plants trained with high-rack culture system showed a superiority for most of the qualitative and quantitative attributes compared to those trained with arching system. The high-rack system resulted in 60% higher extra-quality stems (> 60 cm) compared with the plants trained with arching. It can be concluded that cut roses respond to water deficit through adaptive changes in physiological and morphological levels to reduce water loss without any negative impact at biochemical level.

Keywords: Cut roses, Photosynthesis, Relative water content, Shoot Bending, Water use efficiency.

INTRODUCTION

Cut roses are one of the most commercially important flower crops that are highly vulnerable to damage by water deficit stress (Jin *et al*., 2006; Park and Jeong, 2010). Many studies have highlighted the impacts of global water scarcity on supply of cut flowers (Syros *et al*., 2004; Bolla *et al*., 2010). Previous studies on roses have shown that water availability during production limits photosynthetic potential via stomatal regulation (Williams *et al*., 1999; Bolla *et al*., 2010). As water deficit progresses and leaf water content declines, stomatal conductance to water vapor and net photosynthesis tends to decrease (Chaves *et al*., 2009; Snider *et al*., 2014). On the other hand, in some plant species, water stress decreases net photosynthesis too, but through non-stomatal limitations (Ramalho *et al*., 2014; Novick *et al*., 2016). Under such conditions, mesophyll conductance deceases (Flexas *et al*., 2012) and thus

[1] Department of Horticultural Science and Landscape Engineering, Ferdowsi University of Mashhad, Mashhad, Islamic Republic of Iran.

[2] Department of Agrotechnology, Ferdowsi University of Mashhad, Mashhad, Islamic Republic of Iran.

[3] Department of Water Engineering, Ferdowsi University of Mashhad, Mashhad, Islamic Republic of Iran.

*Corresponding author; e-mail: shoor@um.ac.ir

carboxylation efficiency, RuBP regeneration, and ATP content decrease (Tezara *et al*., 1999; Medrano *et al*., 2002). However, there is an on-going debate about whether water deficit limits CO_2 assimilation rate mainly through stomatal closure and/or metabolic impairment (Galmés *et al*., 2007).

In addition to stomatal response, water deficits may induce the synthesis of compatible solutes such as glycerol, sugar and proline. Among these solutes, proline accumulation in high concentrations in response to a variety of abiotic stresses such as water stress has been reported (Claussen, 2005; Verbruggen and Hermans, 2008). However, conflicting reports have been presented for the proline accumulation in potted roses, indicating that proline has increased or remained unchanged under water deficit stress (Williams *et al*., 1999, 2000).

Besides plant response to water stress, it has been reported by Kim *et al*. (2004) and Matloobi *et al*. (2008) that removing any plant parts or modifying the plant structure of cut roses, such as shoot bending, changes the plant source–sink ratio, which, in turn, can modify the canopy gas-exchange capacity. In this regard, Cirillo *et al*. (2014, 2017) reported that the degree of adaptation of a species to a major abiotic stress such as

drought could also be affected by the canopy shape. In fact, different training systems lead to changes in light harvesting complexes of rose plants through changing foliage density, the ratio of sun/shade leaves, leaf angles and, finally, the canopy leaf distribution pattern (Matloobi, 2012). There are different methods of shoot bending with significantly different effects on quality and yield of cut flower stems. It is reported that flower stem yield in the high-rack (a modified arching system) was much higher than arching training system (Kajihara *et al*., 2009). In the arching system (Figure 1-A), new outgrowing and blind shoots are bent down into the canopy as lower bent shoots. In addition to the above function, the high-rack culture system benefits from some mother stems originating from basal shoots that would bend at about 10–50 cm above the crown of the plant as upper bent shoots (Figure 1-B). Under both arching and high-rack training systems, most of the photosynthates produced by leaves on the lower bent shoot primarily will be translocated to crown and roots, whereas most of the photosynthates produced by the leaves on the upper bent shoot under the high-rack system will be translocated to the mother stem and flower stem (Kajihara *et al*., 2009). Accordingly, it is expected that high-rack system with more bent shoots as
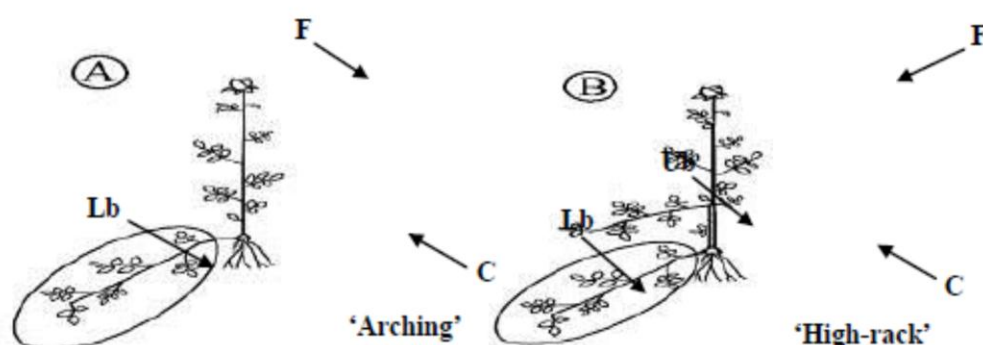
Figure 1. Schematic drawing of rose plant. Abbreviations are, F: Flower; Ub: Upper bent shoot; C: Crown; Lb: Lower bent shoot (Kajihara *et al*., 2009). (A) and (B) represent arching and high-rack culture systems, respectively.

source organs and mother stems as stronger sink organ in comparison with arching system may have the potential to increase Water-Use Efficiency (WUEi) and thereby alleviate detrimental effects of water deficit on greenhouse cut roses.

The main objectives of this study were as follows: (1) Gain a better understanding of some events participating in adaptive processes of greenhouse roses that enable them to cope with water deficit, (2) Determine the effect of water deficit on gas exchange properties and functionality of the photosynthetic apparatus in rose, and (3) Assess whether different training systems can affect differently water-use efficiency and possibly help to alleviate detrimental effects of water deficit on greenhouse cut roses.

MATERIALS AND METHODS

Greenhouse and Climate Control

The experiment was conducted in a fully controlled greenhouse, E–W oriented, located at Ferdowsi University of Mashhad, Iran (Latitude 36° 20' N, longitude 59° 35' E, and 1,065 m asl). The glasshouse was of Venlo type, and was equipped with automated roof windows along with shading screens as well as evaporative cooling pads and exhaust fans to produce target day and night temperatures of 22–28 and 15–18°C, respectively. During winter, the greenhouse was heated by hot water pipes system. One plant was sown in each pot, and cultivation rows were N-S oriented.

Plant Materials

Rooted cuttings of *Rosa hybrida* 'Club-Nika' raised in Jiffy pots were transferred to polyethylene pots (4 L volume) filled with an artificial substrate (granulated perlite) at density of approximately 8 plants m^{-2} on 5 March 2015 and grown in an open hydroponic system. The primary shoots

were bent from the stem bases of the plants at the stage of pea-sized flower bud as the lower bent shoot (Figure 1) on 20 April 2015 in both training systems. All flower buds of the bent shoots were removed immediately after bending. Only one shoot was allowed to grow on all plants in both training systems. Finally, on 27 May, new shoots raised from the crown were bent downwards at height of 20 cm from the crown as the upper bent shoots. In arching system, when new shoots developed from the crown, they were bent downwards from stem bases of the plants again and primary bent shoot was removed. The nutrient solution contained (in mmol L^{-1}): NO_3^-, 13.2; $H_2PO_4^-$, 1.5; SO_4^{2-}, 1.2; NH_4^+, 0.9; K^+, 4.9; Ca^{2+}, 4.5; Mg^{2+}, 1.1. The target pH value of the nutrient solution was maintained between 5.5 and 6.0, and the electrical conductivity was maintained between 1.5 and 2 dS m^{-1}. Plants were fertigated using a drip irrigation system. The first harvest occurred in 6 July 2015 and lasted until December 22 of the same year.

Irrigation Control

Drip irrigation was controlled by a timer. The plants were irrigated 4–6 times per day depending on seasons with a water supply rate of 4 L h^{-1} (Figure 2). In this work, the model described by Katsoulas *et al.* (2006) was used to predict the amount of water applied (E) of rose plants grown under the greenhouse conditions (Equation 1).

$$E = \frac{Tr}{1-D} \qquad (1)$$

Where, D is the Drainage rate and T_r is the crop Transpiration rate in kg m^{-2} estimated using the simple relation as Equation (2):

$$T_r = \backslash R_{Go} \qquad (2)$$

Where, R_{Go} is accumulative solar Radiation (kJ m^2) Outside the Greenhouse (Figure 3) and the coefficient $\backslash$ is given by Equation (3):

$$\backslash = K_c \tau \alpha / \lambda \qquad (3)$$

Where, K_c is the crop coefficient, τ is the greenhouse cover transmission to solar radiation, α is the evaporation coefficient,
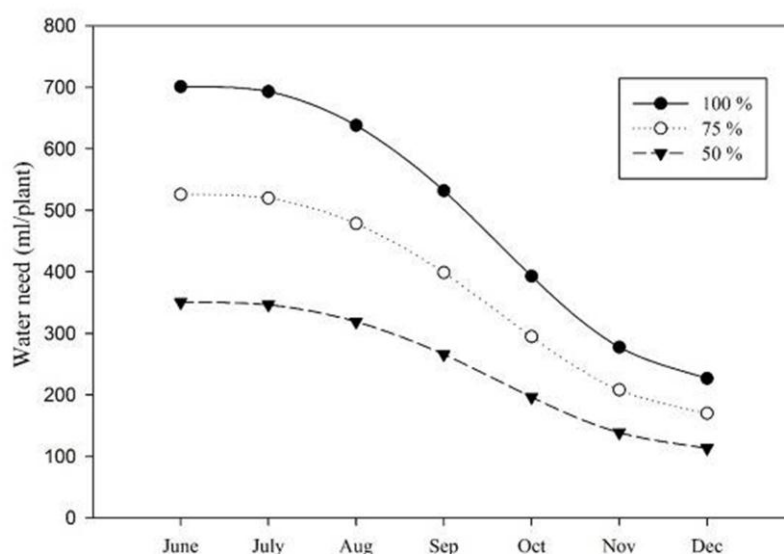
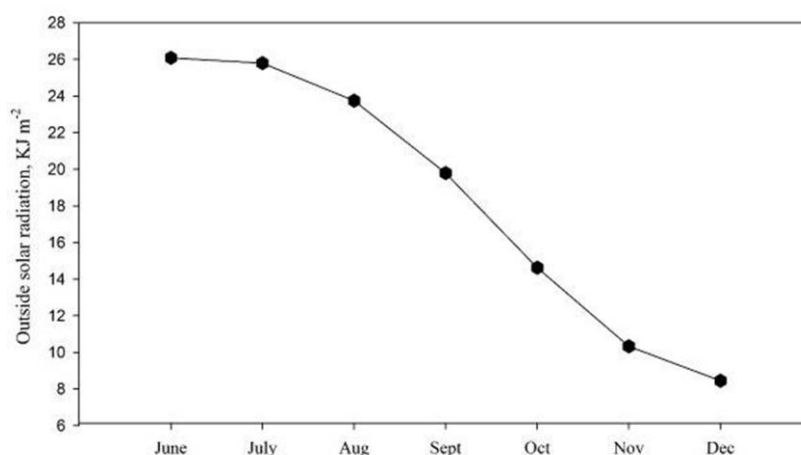**Figure 2.** Water needs (mL plant^{-1}) of a rose crop, calculated using Equation (1).

Figure 3. Outside solar radiation (KJ m^{-2}).

and λ is the latent heat of vaporization of water in kJ kg^{-1}. In the treatment of 100% irrigation needs, drainage rate was considered as about 25% in order to maintain optimal conditions of water supply to the plants.

The greenhouse cover transmission to solar radiation τ was calculated as the mean ratio of incoming to outside solar radiation (0.9). Taking into account that the rose plants were not fully developed, the crop coefficient K_c was considered 0.8, while the evaporation coefficient "a" was taken equal

to 0.6, as is usually observed for greenhouse crops (Katsoulas *et al*., 2006; Baille, 1999).

Data Collection

In this experiment, cut flower production (the number of extra-quality stems and the total number of flower stems) was monitored from 10 July to 24 December 2015. Generally, shoots longer than 60 cm were considered as extra-quality stems (Katsoulas *et al*., 2006). At the end of the experimental period, about 180

days after the last severe shoot bending, traits including flower diameter, fresh weight of flower stem, leaf area, relative water content, photosynthetic gas exchange (including net CO_2 assimilation rate, transpiration rate, stomatal conductance and intercellular CO_2 concentration), chlorophyll contents [chl *a*, chl *b* and total chl (*a+b*)], and proline content were also measured.

Relative Water Content

RWC was calculated using the following equation (Yamasaki and Dillenburg, 1999, Equation 4).

% RWC= (FW-DW)/(TW-DW)×100 (4)

Where, FW is the leaf Fresh Weight (g), DW the leaf Dry Weight (g) and TW the leaf Turgid Weight (g). Turgid weight was determined by weighing the leaf after 12 hours of immersion in distilled water at room temperature. Leaf dry weight was obtained after leaves were kept 48 hours at 70°C in an oven.

Proline Content

Proline content was determined based on the method of Bates *et al*. (1973), with modifications using L-proline as standard. Fresh leaves (0.1 g) from the upper five-leaflet leaves were incubated with 5 mL 3% (w/v) sulfosalicylic acid at 100°C for 10 minutes and each 2 mL of extracts was mixed with 0.2% (w/v) ninhydrin reagent containing 70% (v/v) glacial acetic acid and incubated at 100°C for 60 minutes. The reaction was cooled under running tap water, the colored product was extracted with 4 mL toluene, and the absorbance of the toluene phase was measured at 520 nm. The results were expressed as µmol g^{-1} FW.

Chlorophyll Measurements

Chlorophyll content (Chl *a*, Chl *b* and Chl *a+b*) was determined by spectrophotometric method according to Şükran *et al*. (1998). Leaf samples (consisting of three disks) were collected in early morning from five-leaflet compound leaves and were extracted with 10 mL 99% methanol (v/v%). Finally, absorption of the extraction was read at 666 and 653 nm. The results were expressed as mg g^{-1} FW.

Gas Exchange Measurements and Water Use Efficiency

Net CO_2 assimilation rate (P_N, µmol m^{-2} s^{-1}), intracellular CO_2 concentration (C_i, mmol mol^{-1}), transpiration (E, mmol m^{-2} s^{-1}) of the top fully expanded leaves were measured using a portable gas analyzer (LCi, ADC Bio Scientific Ltd, England). Leaf stomatal conductance (gs, mmol m^{-2} s^{-1}) was measured with a diffusion porometer (MK, Delta-T Devices, and Cambridge, UK). The measurements were taken between 10:00 AM and 01:00 PM, and for each treatment, 2–3 leaves were sampled from 4 individual plants. All measurements were carried out at 25°C and at saturating photosynthetic photon flux density (1,000 µmol m^{-2} s^{-1}) under ambient air CO_2 concentration (360 ppm). Gas exchange measurements were performed on five-leaflet compound leaves (the fourth or fifth from the top of the flowering shoot). Instantaneous Water Use Efficiency (WUEi) was calculated by the ratio between P_N and E (P_N/E).

Statistical Analysis

In this experiment, the effects of three irrigation regimes (50, 75, and 100% of water requirement) combined with two training systems (arching and high-rack) were investigated in factorial arrangement based on a randomized complete block design with four replicates. All the studied traits were subjected to analysis of variance. Statistical analysis of data was carried out by SPSS software (Version 16.0, SPSS Inc.)

and means comparison was performed by Tukey test (P≤ 0.05).

RESULTS

Biometrical Traits and Biomass

Fresh and dry weights of flowering stems significantly decreased in water-stressed plants in comparison with the control plants (by 19 and 36% in 75 and 50% of irrigation needs, respectively, compared to the control treatment). The highest and the lowest fresh and dry weights of flowering stem were monitored for the plants irrigated with 100 and 50% of water needs, respectively (Table 1). The results also indicated that water deficit significantly decreased total leaf area (by 26 and 38% in 75 and 50% of irrigation needs, respectively, compared to the control treatment), the most important factor affecting crop productivity (Table 1). Furthermore, flower diameter significantly decreased under the applied water stress levels. The highest flower diameter (28.8 mm) was obtained in plants irrigated with 100% of water need, whereas the lowest one (25.7 mm) was observed in the plants receiving 50% of water need (Table 1).

Furthermore, training systems had a significant effect on morphological attributes, such that plants trained with high-rack system showed higher fresh and dry weights of flowering stem, flower diameter, and leaf area than the arching system (Table 1).

Cut Flower Production and Quality

Stem length is considered as the most important indicator for commercial value in cut-flower rose production. In this research, we observed that water stress negatively affected the total number of extra-quality stems (> 60 cm), such that the highest number of extra-quality stems was obtained in well-irrigated plants, whereas the lowest one was observed in the plants irrigated with 50% of water need (Table 1). However, the total number of flower stems was not affected significantly by water regimes (data not shown). In this study, the plants trained with high-rack system showed a superiority over arching training for most of the marketable attributes of cut roses. The high-rack system resulted in 60% higher extra-quality stems (> 60 cm) compared with the plants trained with arching training system (Table 1).

Table 1. Analysis of variance and means comparison for flower, leaf, and stem attributes of *Rosa hybrida* 'Club-Nika' plants irrigated with three irrigation regimes and trained with two systems.

	Flowering stem (g DW plant^{-1})	Flowering stem (g FW plant^{-1})	Leaf area (cm^2 plant^{-1})	Flower diameter (mm)	Extra quality stem (> 60) (n plant^{-1})	Total flower stem (n plant^{-1})
Irrigation regimes (I)						
100	23.23 a	88.1 a	1310.5 a	28.79 a	3.12 a	6.37
75	18.78 b	71.5 b	972.2 ab	27.10 b	2.75 a	6.25
50	14.32 c	56.6 c	813.53 b	25.72 c	1.00 b	6.00
Training systems (T)						
Arching	17.28 b	65.1 b	924.07 b	26.55 b	1.75 b	5.83 b
High-rack	20.27 a	79.1 a	1140.11 a	27.89 a	2.83 a	6.58 a
I	***	***	**	***	***	NS
T	*	**	*	**	**	*
I×T	NS	NS	NS	NS	NS	NS

$^{a-b}$ Different letters within each column indicate significant differences according to Tukey test (P≤ 0.05). *; **, ***: Significant at P≤ 0.05, 0.01, and 0.001, respectively; NS: Non-Significant.

Water Relations

RWC declined significantly with increasing water stress (Table 2). Even well-irrigated plants showed a RWC below 100%. There were no significant differences between training systems with respect to RWC (Table 2).

Leaf Gas Exchange

Leaf photosynthetic parameters [Net CO_2 assimilation rate (P_N), stomatal conductance (g_s) and transpiration (E)] were significantly influenced by water stress (Table 2), whereas Water Use Efficiency (WUEi) and intercellular CO_2 concentration (C_i) were unaffected (Table 2). In general, plants subjected to severe water stress exhibited about 27% lower net photosynthesis rate than the plants irrigated with 100% of water need. None of the photosynthetic parameters were affected by the training systems and water stress×training system interaction (Table 2).

Photosynthetic Pigments and Proline Accumulation

In the three water treatments, no significant differences were noticed regarding Chl content (Chl *a*, Chl *b*, Chl *a+b*) (Table 3). Furthermore, proline concentration remained almost unchanged under water deficit (Table 3). As can be seen from Tables 3, photosynthetic pigments and proline concentration were not affected by training systems and water stress×training system as well (Table 3).

DISCUSSION

Water deficit significantly reduced the morphological parameters such as fresh and dry weights of flowering stem, flower diameter, and leaf area (Table 1). Similar to this study, Katsoulas *et al.* (2006) reported that irrigation frequency influenced fresh and dry weights of cut roses because the total fresh and dry weights of cut flower shoots were about 33% higher under high irrigation frequency as compared to low

Table 2. Analysis of variance and means comparison Relative Water Content (RWC), Net Photosynthetic rate (P_N), stomatal conductance (gs) transpiration rate (E), intercellular CO_2 concentration (*C*i) and Water Use Efficiency (WUEi) of *Rosa hybrida* 'Club-Nika'plants irrigated with three irrigation regimes and trained with two systems.

	RWC (%)	P_N $\mu mol\ m^{-2}\ s^{-1}$	gs $mmol\ m^{-2}\ s^{-1}$	E	Ci $mmol\ mol^{-1}$	WUEi $\mu mol\ CO_2\ mmol^{-1}\ H_2O$
Irrigation regimes (I)						
100	91.32 a	23.79 a	25.22 a	7.78 a	263.9	3.14
75	90.02 ab	20.94 ab	23.72 ab	6.22 a	236.5	3.34
50	87.99 b	18 b	21.88 b	5.25 b	243.7	3.46
Training systems (T)						
Arching	89.41	21	23.97	6.45	240.9	3.25
High-rack	90.14	20.8	23.24	6.39	255.1	3.38
I	*	***	**	***	NS	NS
T	NS	NS	NS	NS	NS	NS
I×T	NS	NS	NS	NS	NS	NS

[a-b] Different letters within each column indicate significant differences according to Tukey test (P≤ 0.05). *; **, ***: Significant at P≤ 0.05, 0.01, and 0.001, respectively; NS: Non-Significant.

Table 3. Analysis of variance and means comparison of chlorophyll content and proline concentration of *Rosa hybrida* 'Club-Nika' plants.

	Ch a	Ch b	Total Ch	Proline concentration
Irrigation regimes (I)				
100	14.50 a	14.63 a	29.14 a	0.040 a
75	14.27 a	14.37 a	28.61 a	0.043 a
50	14.14 a	14.09 a	28.23 a	0.046 a
Training systems (T)				
Arching	13.93 a	14.29 a	28.23 a	0.042 a
High-rack	14.66 a	14.43 a	29.09 a	0.043 a
I	NS	NS	NS	NS
T	NS	NS	NS	NS
I×T	NS	NS	NS	NS

[a-b] Different letters within each column indicate significant differences according to Tukey test (P≤ 0.05). *; **, ***: Significant at P≤ 0.05, 0.01, and 0.001, respectively; NS: Non-Significant.

irrigation frequency. Morphological parameters like fresh and dry weights were reported to be significantly reduced under water stress in several higher plants (Shao *et al*., 2008). Alvarez *et al*. (2013) noticed a decrease in growth and biomass traits in potted geranium when exposed to regulated deficit irrigation regimes. The reduction in fresh weight under water deficit may be due to the considerable decrease in plant growth, net photosynthetic rate as well as suppression of cell expansion and cell growth due to the low turgor pressure (Idrees *et al*., 2010; Shao *et al*., 2008; Taiz and Zeiger, 2006). Cell expansion can only occur when turgor pressure is greater than the cell wall yield threshold (Shao *et al*., 2008).

Water availability during growth has been shown to affect biomass allocation as well as leaf area. Several studies have been devoted to plants grown and developed under water deficit, where, in general, a decreased total leaf area has been observed (Liu and Stützel, 2004; Shamshiri *et al*., 2011; Farooq *et al*., 2009), as compared to plants grown with adequate water supply. The higher leaf area of well-irrigated plants increases the transpiration rate during growth, facilitating nutrient uptake (Cramer *et al*., 2009), long-distance signaling (Jia and Zhang, 2008), as well as phloem assimilate import (Lacointe and Minchin, 2008).

Our results are in agreement with the findings of Fascella *et al*. (2015) on cut rose 'Red France', who did not observe significant differences in the total number of flower stems between three studied irrigation levels. In contrast to our results, Bolla *et al.* (2010) did not find differences in the number of extra-quality flower stems in cut rose 'Eurored' irrigated with 67% of irrigation need as compared to the control. Increase in stem length depends on cell elongation, which is usually considered the most sensitive growth component to water deficits (Taiz and Zeiger, 2006). Under water deficiency, cell elongation of higher plants can be inhibited by interruption of water flow from the xylem to the surrounding elongating cells (Nonami, 1998). Thus, maintaining a high water content is an objective for rose growers.

The decreased RWC under water deficit stress observed in this study is consistent with the previous studies on *Pittosporum and Viburnum* (Toscano *et al*., 2014), roses (Niu *et al*., 2008; Bolla *et al*., 2010), and *Bougainvillea* (Cirillo *et al*., 2014). Decreasing stomatal conductance may result in a response to either a decrease in leaf water potential or RWC. It has also been reported that decreased RWC under water stress is a direct consequence of water unavailability in root systems or in substrate around the roots (Shalhevet, 1993).

It is well established that under severe water stress, plants reduce photosynthesis, mainly because of stomata closure (Chaves *et al*., 2009), such that plants exposed to severe stress (50% of water need) showed 15% stomatal conductance lower than plants developed at non-stressed conditions (Table 2). There are several reports underlining the stomatal limitation of photosynthesis under drought stress as a primal event (Bolla *et al*., 2010; Buckley, 2005; Saeidi and Abdoli, 2015). Under stress conditions, a reduction in stomatal conductance can have protective effects because it allows the plant to save water and to improve the water use efficiency (Chaves *et al*., 2009). An increasing number of studies confirmed reducing stomatal conductance under water stress (Galmés *et al*., 2007; Chaves *et al*., 2009; Snider *et al*., 2014). Considering no change in intercellular CO_2 concentration, it seems that both stomatal and non-stomatal limitations are involved in adaptive processes of cut roses under water deficit. Many studies have shown that the decrease in the photosynthetic activity under drought stress can be attributed to both stomatal and non-stomatal limitations (Zhou *et al*., 2014; Novick *et al*., 2016; Campos *et al*., 2014).

It is known that plants under increasing water stress respond by an increase in WUEi. This is probably part of an adaptive mechanism to reduce transpiration (Craufurd *et al.*, 1999). However, no significant difference was observed in WUEi in plants exposed to water stress. Our results are in contrast with those of Bolla *et al*. (2010), who reported that WUEi increased in water-stressed rose plants. Moreover, Cirillo *et al*. (2014) indicated that WUE of potted *Bougainvillea* appeared to be strongly affected by water supply, genotype, and canopy shapes. The different results of water deficit regarding WUEi across experiments may be partially due to the different experimental conditions, genotype, or differences in water stress intensity and timing (Cameron *et al*., 2006).

In this study, photosynthetic pigments and proline concentration were not modified

under water stress conditions. A decrease in the chlorophyll concentration would be a typical symptom of oxidative stress and has been observed in water-stressed plants (Hazrati *et al*., 2016), but this was not the case here. In agreement with our findings, Syros *et al*. (2004) in *Gerbera jamesonii* subjected to water limitation did not show differences in Chl concentration. It seems that the loss of metabolic and biochemical activities occurred only at severe stress conditions (Shao *et al*., 2008). This may be attributed to the ability of plants to use both enzymatic and non-enzymatic mechanisms when suffering several levels of oxidative stress (Egert and Tevini, 2002). By contrast, some studies (Claussen, 2005; Bahadoran and Salehi, 2015) indicated a positive correlation between proline accumulation and adaptation to water stress, which is not consistent with the findings of this research. Moreover, proline accumulation under osmotic stress is accompanied by increasing concentration of soluble sugars (Balibrea *et al*., 1997). In this regard, we did not observe any significant effect on total carbohydrate in stressed plants [data not shown]. Therefore, our findings are in agreement with the report of Ghaderi and Siosemardeh, (2011) on strawberry, who mentioned that moderate drought stress affected gas exchange while severe drought stress (25% of field capacity) affected chlorophyll, proline and soluble carbohydrates levels.

Furthermore, training systems had significant effect on morphological attributes, such that plants trained with high-rack system showed higher fresh weight of flowering stem, flower diameter, and leaf area than the arching system (Table 1). In agreement with our results, Kajihara *et al*. (2009) reported that the high-rack culture system resulted in higher quality stems compared with the arching system. As the high-rack culture system had both lower bent shoots and upper bent shoots, which were connected to the mother stem, it contained more bent shoots as source organs and also mother stems as stronger sink organ in comparison with arching culture systems,

thus stimulating the flower stem growth (Kajihara *et al.*, 2009). However, photosynthetic parameters and biochemical characteristics of greenhouse roses were not affected by training systems. The results presented here are in agreement with the results of Matloobi *et al.* (2009), who reported that chlorophyll content did not differ significantly among different training systems. In this study, RWC was not affected by training systems. In this regard, Kim *et al.* (2004) reported that shoot bending changed the water balance of the bent shoot about 1 day after shoot bending; however, these changes decreased over time and disappeared within 3 weeks after bending.

In this research, it was hypothesized that high-rack culture system may ameliorate the negative effects of water stress, due to having more bent shoots and stronger sink organs. However, data obtained in this study did not confirm our hypothesis for any possible indication of interaction between irrigation regime × culture systems. Similarly, Cirillo *et al.* (2014) reported that irrespective of canopy shapes, the water deficit decreased the plant growth parameters of three *Bougainvillea* genotypes.

From the above mentioned results, although it has been concluded that osmoregulation mechanisms might not be used by cut roses 'Club-Nika' to retain turgor during water stress, our results show that both stomatal and non-stomatal components of photosynthesis are involved in adaptive responses to water deficit. Regardless of irrigation regimes, rose plants trained with high-rack culture system showed a superiority in most of the qualitative and quantitative attributes compared with arching training system. Further experiments are needed to better elucidate the specific changes occurring in activity of the enzymes involved in water-deficit under greenhouse conditions.

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کاهش پارامترهای تبادل گازی و کیفیت بازارپسند گل رز (-Club' *Rosa hybrida* 'Nika) تحت تنش آبی صرف نظر از سیستم های تربیتی

ع. دولتخواهی، م. شور، م. بنایان، ع. تهرانی فر، و ا. علیزاده

چکیده

با هدف بررسی فرآیندهای فیزیولوژیکی، مورفولوژیکی و بیوشیمیایی درگیر در فرآیندهای سازگاری رزهای شاخه بریده، پژوهش حاضر به‌صورت آزمایش فاکتوریل در قالب طرح کاملاً تصادفی با سه سطح تنش آبیاری (۱۰۰، ۷۵ و ۵۰ درصد نیاز آبیاری) در ترکیب با دو سیستم تربیت "کمانی و پایه بلند" در شرایط گلخانه انجام شد. نتایج نشان داد که تنش آبی به طور معنی داری صفات کیفی، مورفولوژیکی و هم چنین روابط آبی رزهای شاخه بریده را کاهش داد. سرعت فتوسنتز خالص، میزان تعرق و هدایت روزنه‌ای به طور معنی داری در واکنش به تنش آبی کاهش یافتند، با این حال کارایی مصرف آب و میزان دی اکسید کربن زیر روزنه ای متاثر از تنش آبی واقع نشدند. تنش آبی هم چنین تاثیری بر محتوای کلروفیل برگ ها و تجمع پرولین نشان نداد. نظر به عدم تغییر میزان دی اکسید کربن زیر روزنه‌ای در این پژوهش، به نظر می رسد که هر دو محدویت روزنه ای و غیر روزنه ای در کاهش میزان آسیمیلاسیون دی اکسید کربن تحت تنش آبی موثر هستند. صرف نظر از رژیم های آبیاری، رزهای پرورش یافته با سیستم تربیت پایه بلند برتری محسوسی در صفات کیفی و کمی اندازه گیری شده در مقایسه با سیستم تربیت کمانی نشان دادند. در همین راستا، عملکرد شاخه‌های ممتاز (طول شاخه بیشتر از ۶۰ سانتی متر) در روش پایه بلند در مقایسه با روش مرسوم کمانی افزایش حدود ۶۰ درصدی نشان داد. به طور کلی نتایج این پژوهش نشان داد که رزهای شاخه بریده صرفا از طریق تغییر در سطوح مورفولوژیکی و فیزیولوژیکی و نه تاثیر منفی در سطوح بیوشیمیایی به تنش آبی واکنش نشان دادند.