Hort. Environ. Biotechnol. 55(2):91-96. 2014.
DOI 10.1007/s13580-014-0166-7

ISSN (print) : 2211-3452
ISSN (online) : 2211-3460

Research Report

Shoot Growth and Physiological Disorder of Cut Rose 'Charming Black' as Affected by Drought Stress during Nocturnal Supplemental Lighting

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Received November 26, 2013 / Revised January 23, 2014 / Accepted February 3, 2014

Abstract. Cut rose 'Charming Black' was subjected to three treatments to investigate whether a no-irrigation regime causes drought stress during nocturnal supplemental lighting, and to investigate the effect of drought stress on the growth and quality of the cut flower. During the experiment, shoot length, quality of flower, photosynthetic rate, and chlorophyll and carotenoid contents were measured. Supplemental lighting treatment group grew faster and decreased the percentage of blind shoot; however, several physiological disorders were appeared under different environment conditions. In supplemental lighting (90 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD) treatment group, the shoot grew well and flowered early with irrigation once per hour, but drought stress and a decrease in biomass occurred without irrigation. Water deficit in the no-irrigation regime under supplemental lighting affected the plant growth and caused malformation of the flower. Drought stress also had a negative effect on the photosynthetic machinery with a reduction in carotenoid and chlorophyll contents. As a result the photosynthetic rate was also decreased.

Additional key words: flower quality, growth response, malformed flower, *Rosa hybrida*, water content

Introduction

Optimal irrigation is very important for the greenhouse soilless crops and insufficient irrigation can cause drought stress which has a negative effect on crop productivity. Severe drought stress may result in the arrest of photosynthesis, disturbance of various metabolic processes, and eventually plant death (Jaleel et al., 2008). Drought stress can cause responses in both morphological parameters and photosynthetic pigment of plants. Reductions in shoot length, leaf growth, leaf area, and number of leaves have been reported in many species. On the other hand, drought stress can reduce the photosynthetic rate and produce changes in the ratio of chlorophyll 'a' and 'b' and carotenoids (Anjum et al., 2003; Farooq et al., 2009).

In roses, water is of paramount importance for the plant's productivity, and drought stress has a negative effect on the photosynthetic rate and stomatal conductance, which in turn affects plant growth (Bolla et al., 2009). Drought stress imposed during the petal initiation stage can lead to flower malformation which can affect the flower bud with a reduction in the number of well-formed petals (Chimonidou-Pavlidou, 1996, 1999).

As the cut rose flowers take still a great commercial value in the global floricultural industry, most rose growers use nocturnal supplemental lighting to increase production (Kim and Lee, 2008). It was rare that the rose growers irrigate the crops during the supplemental lighting period due to habitual understanding of a high risk of disease and pest occurrence. However, there has been only limited research regarding whether rose plants need irrigation or not and also whether irrigation during supplemental nocturnal lighting would be beneficial for the plant growth (Kim and Lieth, 2012).

In this study we investigated whether a nocturnal no-irrigation regime causes drought stress or not and the effect of drought stress on the growth and quality of the cut rose cultivar 'Charming Black'. Then, we evaluated the importance and necessity of irrigation during supplemental lighting.

Materials and Methods

Plant Materials and Drought Stress Treatment

The experiment was conducted from December 1, 2012 to February 1, 2013 in an experimental glasshouse, located

at the University of Seoul. Due to high growth rate and sensitivity to the environment conditions, the Korean cultivar *Rosa hybrida* 'Charming Black' was used as a model plant in this experiment. The plants were planted on July 8, 2011 in Rockwool slabs (1 m long, 0.15 m wide and 0.075 m deep, UR Rockwool, Pocheon, Korea) with a 5 plants/m^2 density. The plants were grown using the bending technique (Kool and Lenssen, 1997), which consisted of bending over the stems that were not considered useful for flower stem production.

To investigate the effect of different irrigation regimes on plants under nocturnal supplemental lighting regimes, the experiment was divided into two supplemental light treatment groups, $T_{Control}$ (0 μmol·m^{-2}·s^{-1}, photosynthetically active radiation, PPFD) and T_{SL} (90 μmol·m^{-2}·s^{-1} PPFD). The supplemental lighting periods were 16:00-24:00 h and 02:00-10:00 h with 2 hours of a night break. Since no difference was found between the irrigation and no-irrigation regimes under $T_{Control}$ from a previous study, two irrigation regimes were only applied to the T_{SL} group, no irrigation (40-45% in water content of rockwool slab, $T_{SL\times NI}$) and irrigation once per hour during the supplemental lighting (70-75% in water content of rockwool slab, $T_{SL\times I}$), the water content was measured by FDR method (Coco-100, Mirae Sensor, Seoul, Korea). A high pressure sodium lamp (GEO-NH 400W-L/P, Daekwang, Yeosu, Korea) was used as the light source. The following three treatments were then applied; $T_{Control}$, supplemental 0 μmol·m^{-2}·s^{-1} PPFD with no irrigation; $T_{SL\times NI}$, supplemental 90 μmol·m^{-2}·s^{-1} PAR with no irrigation; and $T_{SL\times I}$, supplemental 90 μmol·m^{-2}·s^{-1} PPFD with irrigation. Pest and disease control measures were used as required.

Plant Growth and Physiological Response Measurement

The rate of shoot growth was measured at every two days until the flower bud appeared. The quality of cut flower was evaluated by the length and weight of cut flower, length of petal, number of petals, and number of days to flowering. The sap flow and stem diameter were measured by using a sap flow meter (ZF-10R, USEEM, Suwon, Korea) as the flower bud appeared.

The photosynthetic parameters were measured on January 17, 2013. Photosynthetic rate, stomatal conductance, and transpiration rate were measured using a portable photosynthesis system (Li-6400, Li-Cor, Lincoln, NE, USA). Leaf chlorophyll content was determined by the absorbance measured at 470, 652, and 655 nm with a spectrophotometer (UV-2450, Shimadzu, Kyoto, Japan). Chlorophyll content (a, b, and a + b) and carotenoid content were computed according to the method described by Lichtenthaler (1987). The statistical analysis included analysis of variance (ANOVA) and was conducted with a statistical analysis software system (version 9.3, SAS Institute Inc., Cary, NC, USA).

Results

The interaction between supplemental lighting and irrigation regimes affected both plant growth and physiological responses. The rose plants under $T_{Control}$ condition showed retarded growth and lower quality as compared to those under the T_{SL} condition. The plant treated with T_{SL} grew faster, but several physiological disorders occurred in the no-irrigation regime.

Plant Growth Responses

In the T_{SL} group, the plants grew faster (Fig. 1) and flowered one week early due to supplemental lighting (Table 1), and the blind shoot was not observed (Table 2). However, physiological disorders were observed with supplemental lighting. Table 2 showed that in the T_{SL} group, a higher percentage of bent peduncle phenomenon was observed than the $T_{Control}$ group, the highest 18.5% was observed in the $T_{SL\times NI}$ group. Moreover, the malformed flowers (petals not formed) appeared in the $T_{SL\times NI}$ group (Table 2). When the irrigation was applied, malformed flower was not observed in the $T_{SL\times I}$ and bent peduncle phenomenon decreased by 9% by this irrigation.

In the T_{SL} treatment group, the plant grew faster under the irrigation regime for most of the measurement periods, and a significant difference was observed between irrigation and no-irrigation regimes after the third week (Fig. 1). When the plants reached to a marketable stage, the shoot length in the

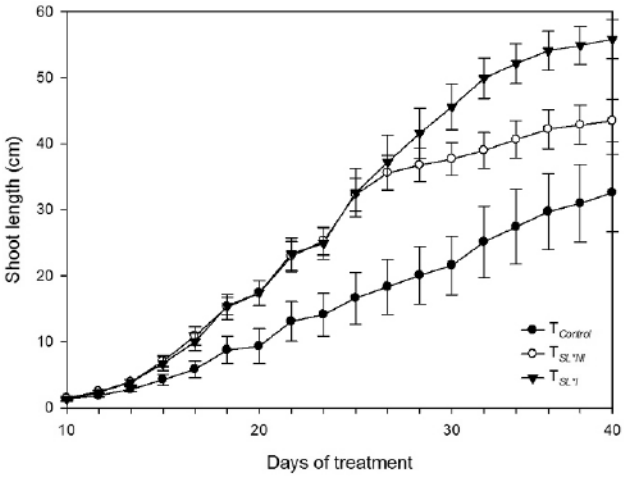

Fig. 1. Effect of irrigation on the shoot elongation in cut rose 'Charming Black' under supplemental lighting condition ($T_{Control}$, no supplemental lighting and irrigation during night time; $T_{SL\times NI}$, supplemental lighting of 90 μmol·m^{-2}·s^{-1} PPFD without irrigation; and $T_{SL\times I}$, supplemental lighting of 90 μmol·m^{-2}·s^{-1} PPFD with good irrigation). Vertical bars mean standard errors (n = 10).

Table 1. Effect of irrigation on shoot growth and quality in cut rose 'Charming Black' under supplemental lighting condition ($T_{Control}$, no supplemental lighting and irrigation during night time; $T_{SL\times NI}$, supplemental lighting of 90 μmol·m^{-2}·s^{-1} PPFD without irrigation; and $T_{SL\times I}$, supplemental lighting of 90 μmol·m^{-2}·s^{-1} PPFD with good irrigation).

Treatment	Days to flowering	Shoot length (cm)	Shoot weight (g)	Stem diameter (cm)	No. of leaves	Leaf area (cm^2)	Peduncle length (cm)	No. of petals	Petal length (mm)
$T_{Control}$	51 b	40.8 c	11.9 c	0.31 c	5.2 b	171.6 c	9.6 b	35.8 b	22.3 b
$T_{SL\times NI}$	43 a	45.6 b	17.5 b	0.38 b	6.7 a	280.4 b	10.0 b	43.7 ab	24.0 b
$T_{SL\times I}$	44 a	59.1 a	29.4 a	0.60 a	7.0 a	425.5 a	13.2 a	47.1 a	34.3 a

[z]Mean separation within columns by Duncan's new multiple range test at p = 0.05 (n = 10).

Table 2. Effect of irrigation on the physiological malformation in cut rose 'Charming Black' under supplemental lighting condition ($T_{Control}$, no supplemental lighting and irrigation during night time; $T_{SL\times NI}$, supplemental lighting of 90 μmol·m^{-2}·s^{-1} PPFD without irrigation; and $T_{SL\times I}$, supplemental lighting of 90 μmol·m^{-2}·s^{-1} PPFD with good irrigation).

Treatment	Blind shoot (%)	Malformed flower (%)	Bent peduncle phenomenon (%)
$T_{Control}$	31	0	4
$T_{SL\times NI}$	0	26	19
$T_{SL\times I}$	0	0	10

Table 3. Effect of irrigation on the photosynthetic rate, and chlorophyll and carotenoid contents of cut rose 'Charming Black' under supplemental lighting condition ($T_{Control}$, no supplemental lighting and irrigation during night time; $T_{SL\times NI}$, supplemental lighting of 90 μmol·m^{-2}·s^{-1} PPFD without irrigation; and $T_{SL\times I}$, supplemental lighting of 90 μmol·m^{-2}·s^{-1} PPFD with good irrigation).

Treatment	Photosynthetic rate (μmol CO_2·m^{-2}·s^{-1})	Chlorophyll (mg·g^{-1} FW)			Carotenoid (mg·g^{-1} FW)
		a	b	Total	
$T_{Control}$	16.10 b	13.91 b	4.58 ab	18.53 b	5.42 a
$T_{SL\times NI}$	14.97 c	6.48 c	1.63 b	7.83 c	2.67 b
$T_{SL\times I}$	17.66 a	21.69 a	6.09 a	27.42 a	5.47 a

[z]Mean separation within columns by Duncan's new multiple range test at p = 0.05 (n = 3).

$T_{SL\times NI}$ increased by 4.8 cm as compared to the $T_{Control}$. In the group $T_{SL\times I}$ there was an increase of 13.5 cm in the shoot length as compared to the $T_{SL\times NI}$. Additionally, the increase in shoot fresh weight due to supplemental lighting and irrigation were 5.6 g and 11.9 g, respectively. There was no significant difference in the petal length between the $T_{Control}$ and $T_{SL\times NI}$. However, the petal length decreased by 1.0 cm when the irrigation was not applied during supplemental lighting. The treatment group without supplemental lighting and plants in the $T_{SL\times NI}$ showed significant reduction in flower stem diameter, with the highest value occurring in the $T_{SL\times I}$ group (Table 1), which also showed a significantly larger leaf area as compared to other treatments.

The water content in different parts of the flower stem can be calculated by comparing the fresh and dry weights. When the $T_{Control}$ and $T_{SL\times NI}$ treatments were compared, the plants with supplemental lighting but without irrigation showed significant reduction in water contents; 6.6% in the leaf, 8.2% in the stem, and 11.1% in the flower. However, in the $T_{SL\times I}$ treatment with the irrigation regime, the water content increased by 11.4% in the leaf, 5.0% in the stem, and 6.6% in the flower (Fig. 2).

The relative value indicated plants under the $T_{SL\times I}$ conditions

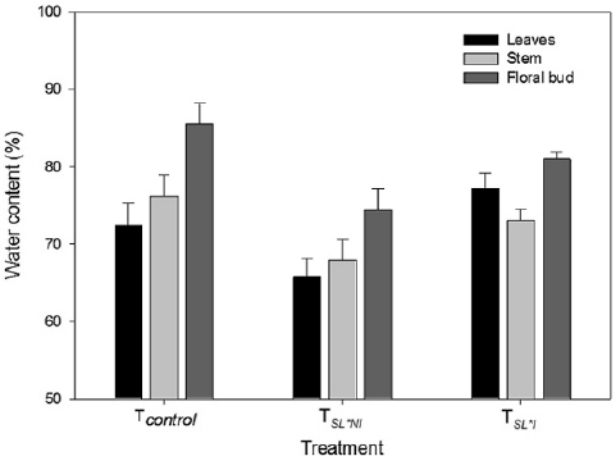

Fig. 2. The water content in the different parts of the flowering shoots in cut rose 'Charming Black' under supplemental lighting condition ($T_{Control}$, no supplemental lighting and irrigation during night time; $T_{SL\times NI}$, supplemental lighting of 90 μmol·m^{-2}·s^{-1} PPFD without irrigation; and $T_{SL\times I}$, supplemental lighting of 90 μmol·m^{-2}·s^{-1} PPFD with good irrigation). Vertical bars mean standard errors (n = 10).

showed better sap flow as compared to the $T_{SL\times NI}$ condition (Fig. 3). There was a progressive increase in stem diameter

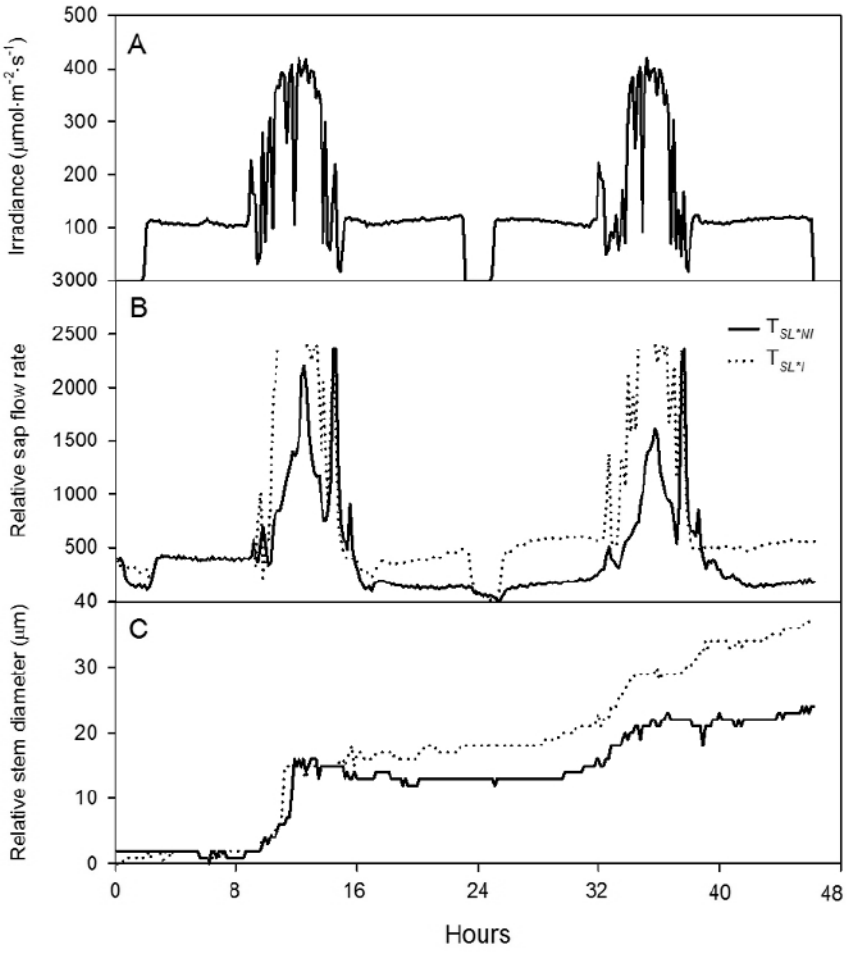

Fig. 3. Real-time changes in the relative values of sap flow and stem diameter of cut rose 'Charming Black' under supplemental lighting condition. $T_{SL\times NI}$, supplemental lighting of 90 μmol·m^{-2}·s^{-1} PPFD without irrigation; $T_{SL\times I}$, supplemental lighting of 90 μmol·m^{-2}·s^{-1} PPFD with good irrigation.

in the $T_{SL\times I}$ group. However, in the $T_{SL\times NI}$ group, the increase was observed only at 10:00 am when the irrigation was restarted and was steadily maintained (Fig. 3).

Physiological Responses

Table 3 shows the photosynthetic characteristics of the plant. Compared with the $T_{Control}$, $T_{SL\times NI}$ caused significant reduction in net photosynthetic rate, whereas in the treatment groups with supplemental lighting (T_{SL}), the net photosynthetic rate increased with irrigation regime.

Plants without nocturnal irrigation ($T_{SL\times NI}$) showed a significant reduction in leaf chlorophyll content when exposed to supplemental lighting, showing decrease of 10.7 mg·g^{-1} FW in total chlorophyll content as compared with the $T_{Control}$. The difference of total chlorophyll content between no-irrigation and irrigation regimes under supplement lighting was 19.6 mg·g^{-1} FW. In addition, the carotenoid content decreased in the $T_{SL\times NI}$ group by 2.80 mg·g^{-1} FW due to supplemental lighting treatment (Table 3).

Discussion

According to the results, the rose plants under the T_{SL} condition showed better growth response. However, several physiological disorders occurred, especially without irrigation. Also drought stress occurred under the no-irrigation regime with supplemental lighting. The $T_{SL\times NI}$ had a significant decrease in shoot length, fresh weight, and quality of flower (short petal length and distorted petals). Comparing the effect of supplement lighting and irrigation regime on the shoot length and shoot fresh weight, shoot length increased by 4.8 cm to 13.5 cm by irrigation. Hence, an increase of 8.7 cm in shoot length occurred under the supplemental lighting regime, implying that under supplemental lighting, irrigation was more important in controlling growth of the plant. The difference of 6.2 g in shoot fresh weight was observed between supplemental lighting and irrigation. Fig. 3 demonstrates that under supplemental nocturnal lighting (16:00-24:00 h and 2:00-10:00 h), no irrigation treatment had decreased

sap flow rate. Even when the irrigation was resumes the next morning; the sap flow increased slowly causing the stem diameter to increase slowly, which led to a thin stem in the $T_{SL\times NI}$.

Previous work showed that when the plant was under a drought stress condition, turgor was the most affected, thus the cell elongation was affected by the stress and resulted in short shoot length (Hale and Orcutt, 1987; Lieth and Burger, 1989). This result could explain the results obtained in the present study. Because the shoot fresh weight decreased in the $T_{SL\times NI}$ (Table 1), the total fresh weight of plants under drought stress was lower than plants treated with normal irrigation as previously reported (Katsoulas et al., 2006). The no-irrigation regime caused a significant reduction in petal length measured as an indicator for rose quality under supplemental lighting (Table 1). The hydraulic architecture of rose plants may possibly provide an explanation for this result. Two regions in the plant showed low resistance to water flow. The least conductance region was at the base of the ovary (distal 15-20 mm of the peduncle) and the second lowest region was the abscission zone also known as the safe zone. Under stress conditions, these two junctions work in conjunction to protect the main axis of the plant by sacrificing peripheral organs (Milburn, 1979; Zimmermann, 1978). Water content in different parts of the flower stem showed that stem, leaf, and flower contained more water in the irrigation regime with supplemental lighting. The water content under the no-irrigation regime decreased by 6.6% in the flower and this might be the reason for shorter flower bud and distorted petals.

A variety of reasons have been reported to increase the incidence of flower malformation in roses. The blind shoot occurring under the $T_{Control}$ condition could have been caused by unfavorable environmental conditions such as low temperature and low light (Halevy and Zieslin, 1969; Moe, 1971, 1988). However, the reduction in number of normal petals and height of flower bud caused by drought stress have also been reported (Chimonidou-Pavlidou, 2004) which is why the flower malformation occurred only in the $T_{SL\times NI}$ group. The bent peduncle phenomenon in roses refers to the enlarged sepal appearing as a phylloid structure, floral organ conversions, and fasciation of the stem. Previous study indicated that bent peduncle phenomenon was caused by asymmetric auxin distribution (Zaccai et al., 2009). Based on the results from the present study, the high value in the T_{SL} group, especially in the $T_{SL\times NI}$, indicated the bent peduncle phenomenon may also be caused by supplemental lighting and drought stress. A previous study demonstrated that malformed buds were caused by drought stress during the stamen initiation stage. Therefore, bent peduncle phenomenon is hypothesized to be affected by drought stress under supplemental lighting in the earlier stage, which warrants further study.

As shown in Table 3, the $T_{SL\times NI}$ treatment showed significant reduction in photosynthetic rate. Under supplemental lighting, photosynthesis can cause the plants to grow faster, but conversely, can cause increased transpiration both during day and night, thus giving rise to more water loss. When there was no irrigation under supplemental lighting, the stomatal closure under drought stress caused a decrease of photosynthetic rate (Bolla et al., 2010). However, the result of stomatal conductance indicated that the reduction in photosynthetic rate was not only caused by stomatal closure, but also by non-stomatal factors such as water imbalance and photosystem dysfunction (Raviv and Blom, 2001). In the present study, reduction in leaf chlorophyll content in the stressed plants may have accounted for the photosynthesis reduction and it also suggests that the reduction in photosynthesis may be attributed to dysfunctions/damages inflicted on the photosynthetic apparatus of photosystem II (PS II) (Neocleous and Vasilkakis, 2007).

In conclusions, water deficit can cause a negative effect on both growth and physiological activities, which have met the findings from the previous work (Bolla et al., 2009). Our results indicate that plants under the $T_{Control}$ condition had retarded growth and decreased quality as compared to plants under the T_{SL} condition. However, the plants in the T_{SL} group grew faster, but drought stress and physiological disorders occurred. In addition, irrigation appeared to be more efficient under the supplemental lighting regime to affect the plant growth and development. As a consequence, irrigation is required under supplemental lighting to prevent drought stress. Further experimentation is necessary to investigate the effect of drought stress at different developmental stages of roses and to determine the developmental stage most sensitive to drought stress, and the optimal irrigation needed during supplemental lighting.

Acknowledgement: This work was carried out with the support of "Cooperative Research Program for Agricultural Science & Technology Development" (Project No. PJ90701504) Rural Development Administration, Republic of Korea.

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