Photosynthetic Daily Light Integral Influences Flowering Time and Crop Characteristics of Cyclamen persicum

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Abstract. This study was carried out to examine the effect of photosynthetic daily light integral (DLI) on the growth and flowering of cyclamen (Cyclamen persicum Mill. ‘Metis Scarlet Red’). Plants with six fully unfolded leaves were grown at 24/16 °C (12 h/12 h) under an 8- or 16-h photoperiod at a photosynthetic photon flux of 50, 100, 150, 200, and 300 μmol·m–2·s–1, which provided seven DLIs: 1.4, 2.9, 4.3, 5.8, 8.6, 11.5, and 17.3 mol·m–2·d–1. Days to first flower decreased from 133 to 75 as DLI increased from 1.4 to 17.3 mol·m–2·d–1, although the acceleration of flowering was less pronounced when the DLI was greater than 5.8 mol·m–2·d–1. Mean leaf and flower number increased from 8.7 to 28.0 and from 0 to 14.7, respectively, as DLI increased from 1.4 to 11.5 mol·m–2·d–1, but there was no further increase under a DLI of 17.3 mol·m–2·d–1. Total dry weight and net photosynthetic rate showed a similar trend as leaf and flower number. We conclude that supplemental lighting can accelerate greenhouse production of potted cyclamen under a low ambient DLI (i.e., less than 12 mol·m–2·d–1).

Cyclamen (Cyclamen persicum L.) is commercially produced from fall until early spring in greenhouses for sales as common winter and spring flowering potted plants (Dole and Wilkins, 2005). In regions at high latitudes (e.g., greater than 35 °N, which includes Korea, the northern half of the United States, and Europe), the mean photosynthetic daily light integral (DLI) can be a limiting factor in the production of many greenhouse crops during the winter and early spring (Faust, 2003). The DLI delivered to greenhouse crops is typically reduced by 40% or more by greenhouse glazing and structure (Hanan, 1998). Therefore, some greenhouse crops are commercially grown under a mean DLI of less than 5 mol·m–2·d–1 (in December and January) to greater than 25 mol·m–2·d–1 (in April and May) (Korzynski et al., 2002). A common target minimum mean DLI for many greenhouse crops is 10 mol·m–2·d–1 at plant canopy level (Faust, 2003).

Increasing DLI increases biomass accumulation, hastens development, and improves final plant quality in many floriculture crops. For example, increasing DLI decreased time to flower of eight species of bedding plants (Faust et al., 2005), in vinca [Catharanthus roseus (L.) G. Don.; Pietsch et al., 1995], and in petunia (Petunia ×hybrida Hort. Vilm.-Andr.; Kaczperski et al., 1991). Days to flower of petunia decreased from 67 to 56 d as DLI increased from 6.5 to 13.0 mol·m–2·d–1 at 20 °C (Kaczperski et al., 1991). A higher DLI increased flower number and size in vinca (Pietsch et al., 1995) and petunia (Kaczperski et al., 1991). In impatiens (Impatiens wallerana L.), plants grown under a DLI of 12 mol·m–2·d–1 had 2.9 more and 0.5 cm larger flowers compared with plants under 5 mol·m–2·d–1 (Faust et al., 2005). Pansy (Viola × Wittrockiana Gams.) had a shorter stem and flower peduncle under a high DLI than a lower one (Niu et al., 2000). High DLI can increase growth rate by promoting photosynthesis (Nemali and van Iersel, 2004). Increasing DLI increased dry matter and flower and floral bud number in rose yarrow (Achillea millefolium L.), gaura (Gaura lindheimeri Engelm. & Gray), lisianthus [Eustoma grandiflorum (Raf.) Shinn], red salvia (Salvia splendens Sell ex Roem. & Schult.), and French marigold (Tagetes patula L.) (Fausey et al., 2005; Islam et al., 2005; Moccaldi and Runkle, 2007). Total dry weight of eight annuals increased, but generally at a decreasing rate, as DLI increased from 5 to 43 mol·m–2·d–1 (Faust et al., 2005). These results suggest that plant developmental rate increases as DLI increases until some threshold beyond which a further increase has little or no effect on developmental rate.

Cyclamen has been classified as a day-neutral plant (Thomas and Vince-Prue, 1997), although some studies indicate that photoperiod, light quality, and light intensity can modify the flowering and subsequent growth of this plant (Erwin et al., 2004; Heo et al., 2003; Neuray, 1973; Widmer and Lyons, 1985). In particular, long days and a high irradiance promoted cyclamen growth and flowering (Cheon et al., 2006; Oh et al., 2008; Rhie et al., 2006). Supplemental lighting from high-pressure sodium lamps at 30 μmol·m–2·s–1 for 20 h per day shortened cultivation time and improved the quality of potted cyclamen (Verberkt et al., 2004).

Previous studies (Cheon et al., 2006; Rhie et al., 2006) showed that an increase in DLI, either by increasing the instantaneous photosynthetic photon flux (PPF) with the same photoperiod, or by extending the photoperiod at the same PPF, promoted growth and flowering of cyclamen. Subsequently, we found in preliminary research that flowering of cyclamen was accelerated by an increase in DLI within a narrow range (Oh et al., 2008). The objective of this study was to investigate the effect of DLI on growth and flowering of cyclamen to assist commercial growers manage light during cyclamen production.

Materials and Methods

Plugs of 12-week-old ‘Metis Scarlet Red’ cyclamen seedlings with five expanded leaves were received from a commercial propagator (Korea-America Plugs Co., Ltd., Jincheon, Korea). Seedlings were transplanted into 7-cm round plastic pots filled with a commercial potting mixture (Sunshine Mix #2; Sun-Gro Horticulture, Bellevue, WA) and moved to plant growth modules [80 × 60 × 40 cm (L × W × H)] for 4 weeks. During this period, plants were grown at 24/ 16 °C (12 h/12 h) under a 12-h photoperiod with a PPF of 200 μmol·m–2·s–1 provided by cool-white fluorescent lamps (FL20EX-D; Wooree Lighting Co., Ltd., Seoul, Korea). Plants were then grown under an 8-h short day (SD, 1000-1800 μm) or a 16-h long day (LD, 0600–2200 μm) at a PPF of 50, 100, 150, 200, and 300 μmol·m–2·s–1 for a total of 10 treatments. The resultant DLIs were 1.4, 2.9, 4.3, 5.8, 8.6, 11.5, and 17.3 mol·m–2·d–1, which were provided by the same type of cool-white fluorescent lamps. The module air temperatures were maintained at 24 °C from 0800 to 2000 μm and 16 °C during the remaining period. Air temperatures were measured using thermocouples connected to data loggers (WatchDog 200; Spectrum.
Technologies, Inc., Plainfield, IL) and were consistently within 2 °C of set points. The PPF in each chamber was measured twice a week using an LI-250A light meter with an LI-210SA photometric sensor (LI-COR Inc., Lincoln, NE) and lamps were adjusted to maintain a constant irradiance. Plants were repositioned randomly in the modules every other week during the experiment.

Cyclamen plants were watered every day for 15 min using an ebb-and-flow automatic irrigation system with Sonneveld solution (Sonneveld and Starver, 1992) that contained macronutrients (mmol L−1) 11.7N–1.5P–5.5K–3.0Ca–0.8Mg–2.0S and micronutrients (μmol L−1) 20Fe–20B–10Mn–3Zn–0.5Mo–0.5Cu. The solution pH was maintained at 5.5 to 6.0 during the treatment period and the electrical conductivity (EC) was maintained at 1.2, 1.6, and 1.4 dS m−1 before flower bud initiation, from bud initiation to flowering, and after flowering, respectively. EC and pH were measured twice a week using an EC meter (CM-53; Takemura Electric Co., Tokyo, Japan) and a pH meter (HM-20P; TOA-DKK, Tokyo, Japan).

Days to first flower was calculated as the number of days from the start of treatment to when the first flower of each plant opened (petals were reflexed backward). At 16 weeks after treatment, the number of leaves (1 cm long or longer) and flowers (with fully reflexed petals) were counted from 20 plants per treatment. At this time, 10 plants per treatment were randomly collected, media was carefully rinsed off, and dry weight was measured after drying at 70 ± 2 °C for 3 d. The remaining plants were grown until first flowering.

Gas exchange in situ was measured with three recently fully expanded leaves on three plants randomly selected in each treatment from 1100 to 1500 ir at 10 weeks after treatment. Net CO2 assimilation rate was measured using a portable photosynthesis system (Li-6400; LI-COR Inc.) equipped with an infrared gas analyzer. The leaf area was enclosed by the chamber was 6 cm2. The leaf chamber was maintained at 20 °C and a relative humidity of 40% during the measurements. Net CO2 assimilation rate was determined for each leaf for 30 min. The concentration of applied CO2 was maintained at 360 μmol mol−1.

Collected data were analyzed by analysis of variance and general linear models procedures using the SAS program (SAS Institute Inc., Cary, NC). Regression analysis and graph modules were analyzed using Sigma Plot software (SPSS, Inc., Chicago, IL).

Results

An increase in DLI promoted flowering of ‘Metis Scarlet Red’ cyclamen. Days to first flower decreased from 133 to 75 as DLI increased from 1.4 to 17.3 mol m−2 d−1 (Fig. 1). However, the effect of an increase in DLI was most notable when DLI increased from 1.4 to 5.8 mol m−2 d−1; a further increase had only a small effect on flowering time. Three of the DLIs (2.9, 5.8, and 8.7 mol m−2 d−1) were delivered by both SD and LD. The only effect of photoperiod on flowering time occurred under the DLI of 2.9 mol m−2 d−1, when flowering was earlier under the 16-h LD (with a PPF of 50 μmol m−2 s−1) compared with the 8-h SD (with a PPF of 100 μmol m−2 s−1).

The number of leaves after 16 weeks of growth increased significantly as DLI increased within the range studied (Fig. 2A). Plants also developed more flowers as the DLI under which they were grown increased (Fig. 2B). Leaf and flower number were correlated with an R2 of 0.92 (P < 0.0011; data not shown). However, flower number of plants under DLIs of 11.5 and 17.3 mol m−2 d−1 were similar. Plants had increased growth (dry matter accumulation) as DLI increased from 1.4 until ≈11 or 12 mol m−2 d−1 (Fig. 3). There was no statistical difference in dry weight of plants grown under a DLI of 11.5 and 17.3 mol m−2 d−1. Similarly, the photosynthetic rates in situ of ‘Metis Scarlet Red’ cyclamen increased with an increase in DLI (Fig. 4). There was little difference in instantaneous photosynthetic rate of plants grown under LD and SD at the same PPF.

Discussion

Flowering of ‘Metis Scarlet Red’ cyclamen was increasingly delayed as DLI decreased, especially when less than 5.8 mol m−2 d−1. Increasing DLI decreased time to flowering in many other floriculture crops, including ageratum (Ageratum houstonianum L.), celosia (Celosia argentea var. plumosa L.), impatiens, geranium (Pelargonium ×hortorum L.H. Bail.), French marigold, pansy, petunia, red salvia, snapdragon (Antirrhinum majalis L.), stock (Matthiola incana L.), vinca, and zinnia (Zinnia elegans L.) (Adams et al., 1998; Armitage et al., 1981; Dansereau et al., 1998; Erickson et al., 1980; Faust et al., 2005; Graper and Healy, 1991; Kaczperski et al., 1991; Moccaldi and Runkle, 2007; Niu et al., 2000; Pietsch et al., 1995; Pramuk and Runkle, 2005a, 2005b), Days to flowering in all of these plants, except for impatiens, decreased as DLI increased to more than 15 or 20 mol m−2 d−1. Similarly, increasing DLI to more than 10 mol m−2 d−1 did not promote the flowering of begonia (Begonia ×semperflorens-cultorum L.) and impatiens (Faust et al., 2005), similar to our results with cyclamen.

Loehrlein and Craig (2004) classified eight cultivars of Regal geranium (Pelargonium ×domesticum L.H. Bail.) into the following three categories according to floral initiation response to DLI: irradiance-responsive (IR), time-responsive (TR), and nonresponsive (NR) plants. The number of days to flowering of IR plants decreases with increasing DLI; TR plants initiate flowering in response to time and temperature rather than DLI or cumulative irradiance. Vogelegaz and Verberkt (1990) reported that supplemental lighting for 16 h at ≥30 μmol m−2 s−1 reduced cultivation time of cyclamen by 6 weeks when grown at a 16-h day/8-h night temperature of 14 to 16/12 to 14 °C. Therefore, at least this cultivar of cyclamen can be categorized as an IR plant from our results and that of Vogelegaz and Verberkt (1990).

Increasing DLI improved plant quality of ‘Metis Scarlet Red’ cyclamen by increasing the leaf number, flower number, and dry weight. Similarly, the total number of flowers and flower buds increased with increasing DLI in miniature rose (Rosa L.) (Mortensen and Moe, 1995), rose yarrow and gaura (Faust et al., 2005), primula (Primula vulgaris Huds.; Karlsson, 2002), celosia and impatiens (Pramuk and Runkle, 2005a), salvia and marigold (Moccaldi and Runkle, 2007), geranium (White and Warrington, 1984), lisianthus (Islam et al., 2005), and vinca (Pietsch et al., 1995).

As DLI increased from 1.4 to 17.3 mol m−2 d−1, total dry weight of cyclamen increased. An increase in dry matter production with increasing DLI has been reported by Pramuk and Runkle (2005b) and Faust et al. (2005) in several floriculture crops. Similarly, dry weight of wax begonia increased linearly as DLI increased from 5.3 to 19.4 mol m−2 d−1 (Nemali and van Iersel, 2004). Similar responses have also been reported in petunia (Lieth et al., 1991), other studies with wax begonia (Graper and Healy, 1990; Kessler et al., 1990), lisianthus (Islam et al., 2005), geranium (White and Warrington, 1984), and rose yarrow (Faust et al., 2005).

We also quantified how increasing DLI promoted cyclamen growth by increasing photosynthesis. As DLI increased from 1.4 to 17.3 mol m−2 d−1, photosynthetic rate in situ increased but at a decreasing rate. Nemali and van Iersel (2004) reported that high DLI increased whole plant photosynthesis and carbon use efficiency in wax begonia. Our regression analysis indicates that net photosynthetic rate of cyclamen was highest when grown under DLI of ≥17 mol m−2 d−1.

Moe (1994) divided the response of horticultural ornamental species to DLI into
4. The effect of photosynthetic daily light integral on in situ net CO₂ assimilation rate of cyclamen ‘Metis Scarlet Red’ after 10 weeks of treatments. Plants were grown under an 8-h short day (SD) or 16-h long day (LD). Error bars indicate se.

Our data indicate that increasing DLI promotes flowering and improves plant quality by increasing dry matter and leaf and flower number. Therefore, supplemental lighting to increase DLI can be useful in greenhouse production of potted cyclamen in temperate climates from late fall until early spring, when the DLI delivered to crops is less than 10 mol·m⁻²·d⁻¹. ‘Metis Scarlet Red’ cyclamen is an irradiance-responsive plant in which days to flowering decreases as DLI increases, but there is little or no effect of increasing DLI above ≈12 mol·m⁻²·d⁻¹. Additional research performed in greenhouses exposed to natural sunlight, with supplemental lighting from a more common lamp type used in commercial greenhouses (e.g., high-pressure sodium lamps), is needed to compare our results in growth chambers with a more commercial environment.

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