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Cost-efficient light control for production of two campanula species

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ABSTRACT

A cost-efficient light control system based on weather forecasts, electricity prices and daily photosynthesis integral (DPI) was evaluated for application in the commercial production of the long-day (LD) plant *Campanula portenschlagiana* 'Blue Get Mee' and *C. cochlearifolia* 'Blue Wonder'. Experiments were conducted under both autumn and spring conditions and included four treatments. Three treatments were controlled by the software system DynaLight Desktop which automatically defined the most cost-efficient use of supplemental light, -based on a predefined set point of DPI, forecasted solar irradiance and the market price on electricity. The set points of DPI in the three treatments were 300, 450 and 600 mmol CO_2 m^{-2} leaf d^{-1} and the treatments were compared with a traditional LD 19-h treatment. The DPI-based light control strategy resulted in very irregular light patterns including daily periods of solar irradiance combined with supplemental light in low light periods and a night period interrupted by irregular light breaks (NB-lighting). Both campanula species flowered in the DPI-based treatments during spring, but the flowering percentage was low and non-uniform during autumn. This was caused by a combination of the irregular light, low natural light intensities and a decrease in daily light integral (DLI), and could be restored by maintaining a continuous 19 h photoperiod with incandescent lamps (<5 μmol m^{-2} s^{-1}), illustrating that photoperiod was an important factor for flowering in LD species grown under low light intensities. Growth in terms of carbon gain was marginally affected by the irregular light and a 25% reduction in electricity costs was achieved without major reductions in plant quality in spring. Our results illustrate that plant production of LD species can be maintained in a cost-efficient light control system where the use of supplemental light is based on weather forecasts and electricity prices.

1. Introduction

Protected plant production systems in the northern hemisphere increasingly rely on the addition of supplemental light both to extend the day length and to increase the daily light integral (DLI). However, as electricity prices vary on an hourly basis, the sustainable and optimal use of supplemental light is highly linked to the use and cost of electricity. In a recent developed light control system the timing and use of supplemental light is based on weather forecasts and electricity prices and controlled by predefined set points for daily photosynthesis integral (DPI) (Markvart et al., 2009; Kjaer and Ottosen, 2011). This means that the daily light hours will not occur continuously, but instead divided into periods of solar irradiance combined with supplemental light in low light periods during the day, and a night period interrupted by irregular light breaks (NB lighting). Furthermore, the length of the NB lighting periods is based on set points for DPI and forecasted solar irradiance.

Campanula portenschlagiana 'Blue Get Mee' and *C. cochlearifolia* 'Blue Wonder' are long-day (LD) plants and recommended greenhouse production conditions for different campanula species include a minimum photoperiod of 14 h (Moe and Heide, 1985). However, rapid and uniform flowering can also be achieved when campanula and various other species of LD plants are illuminated with incandescent light (2–5 μmol m^{-2} s^{-1}) for 4 h of NB lighting in the middle of a 12 h night (e.g. 2200–0200 h) or continuous light is provided by incandescent lamps during the entire night (Moe et al., 1991; Runkle et al., 1998). If the periods of NB lighting are shorter than 4 h, flowering may become non-uniform and delayed in some species (Runkle et al., 1998), and if the periods are longer than 4 h, the number of flowers may not increase further (Albrecht and Lehmann, 1991; Hamaker et al., 1996). Cyclic lighting, in which lamps are turned on and off during the 4 h of NB lighting in the middle of the night provide advantages in the form of energy savings, but flowering in some LD species may be incomplete, delayed or non-uniform compared to plants grown under continuous incandescent light (Bickford and Dunn, 1972; Blanchard and Runkle, 2010).

Abbreviations: DLD, Daily Light duration; DPI, Daily photosynthesis integral; NB, Night break.

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Our alternative approach is based on controlling the timing and use of supplemental light in relation to hourly changes in electricity prices and forecasted solar irradiance in combination with predefined DPI's. The advantage of this approach is energy saving in high-cost periods during the day due to reduced use of supplemental light, but the occurrence of shorter day (SD) may delay flowering or provide incomplete and non-uniform flowering due to a highly unpredictable light pattern. Plants have a circadian rhythm based on light-regulated processes (Dodd et al., 2005; Resco et al., 2009). Our hypothesis is that the irregular changes in the distribution and duration of the light periods will disturb the circadian rhythm. However, these disturbances will not affect overall plant dry matter production as recently reported for the SD plant chrysanthemum (Kjaer and Ottosen, 2011). Furthermore, several different strategies of NB lighting have not delayed flowering in campanula (Moe et al., 1991; Runkle et al., 1998; Blanchard and Runkle, 2010), suggesting that the development of induced flowers in this species and other LD plants depend more on the duration of light than on the distribution of light during the day. The aim of the present study was to evaluate whether the occurrence of SD and a highly unpredictable light pattern had any negative effect on growth and development on campanula LD plants.

2. Material and methods

2.1. Plant material and growth conditions

600 plantlets of *C. portenschlagiana* 'Blue Get Mee' and *C. cochlearifolia* 'Blue Wonder' were received from a commercial grower (PKM A/S, Odense, Denmark) in 10.5 cm pots. Plants were fertigated by flooding every second day with nutrient solution consisting of 5.7 mM $NaNO_3$, 12.6 mM NH_4NO_3, 8.9 mM KCl, 0.7 mM Fe-EDTA, 47.6 mM KNO_3, 0.4 mM $(NH_4)_2SO_4$, 3.4 mM $(NH_4)H_2PO_4$, 2.6 mM KH_2PO_4, 5.8 mM $MgSO_4$ and micronutrients.

The experiment was carried out from 9 October to 18 December 2009 and repeated from 12 January to 26 March 2010 in a greenhouse located at the Department of Horticulture, University of Aarhus (Aarslev, Denmark, Lat 55° N). During this period, the natural day length decreases from 11 h in early October to 7 h in mid December, and increases from 7.5 h to 12.5 h from January to late march. The experiment was performed in two compartments each 9.9 × 7.6 m which were subdivided in two units to allow for a total of four treatments with different light settings. The set point for CO_2 was 700 $\mu l\, l^{-1}$ during the light periods (day or supplemental light), the night temperature was 15 °C and the average day temperature was 18 °C. Supplemental light provided ≈60 $\mu mol\, m^{-2}\, s^{-1}$ at table level by high-pressure sodium lamps (SON-T agro, 600 W, Philips, Eindhoven, The Netherlands).

The supplemental light control strategy was the same in all treatments and based on a leaf photosynthesis model that calculated optimum photosynthesis at a given light intensity as a function of leaf temperature and CO_2 concentration (Aaslyng et al., 2003). The set points were adjusted every 10 min based on actual irradiance and temperature, in an attempt to optimize the CO_2 level based on the leaf photosynthesis model, with the overall aim of reaching 80% of the optimum photosynthesis. In the LD treatment, the continuous 19-h light period was maintained from 2200 h to 1700 h by turning on the supplemental light when the photosynthetic photon flux density (PPF) was below 198 $\mu mol\, m^{-2}\, s^{-1}$. In the three other treatments the timing and use of supplemental light was controlled by 24-h forecasted solar irradiance and hourly changes in electricity prices during the hours from 2000 h to 1700 h by the software package developed in connection with the project (DynaLight Desktop, University of Southern Denmark, Odense, Denmark).

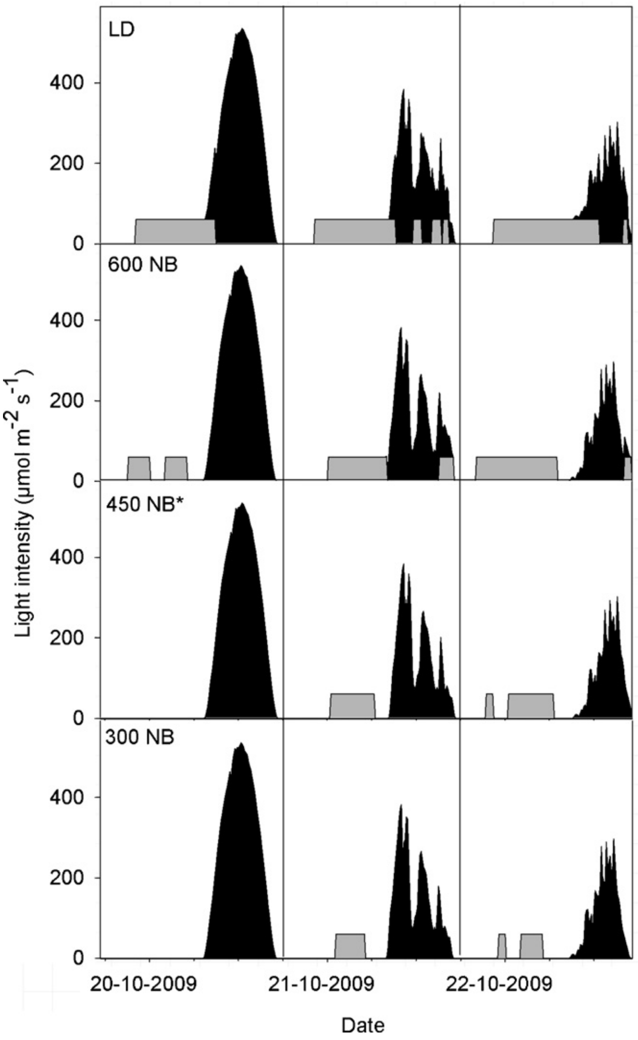

Fig. 1. An example of daily light duration (DLD) and light intensities ($\mu mol\, m^{-2}\, s^{-1}$) of solar irradiation (dark areas) and supplemental light (grey areas) in four greenhouse treatments with different light control strategies. The treatments were long day (LD) with a day length of ≈19 h, 600 NB with a set point for daily photosynthesis integral (DPI) of 600 mmol CO_2 m^{-2} leaf s^{-1}, 450 NB* (DPI ≈450 mmol CO_2 m^{-2} leaf s^{-1}) and including ≈19 h incandescent light (<5 $\mu mol\, m^{-2}\, s^{-1}$), and 300 NB (DPI ≈300 mmol CO_2 m^{-2} leaf s^{-1}). NB refers to irregular night breaks of light.

At the beginning of the experiment, a set point for the daily photosynthesis integral (DPI) was defined for each treatment in the DynaLight program. For the three treatments, the DPI's were 300, 450 and 600 mmol CO_2 m^{-2} leaf d^{-1}. Every day at 1900 h, the supplemental light settings for the subsequent 24 h was calculated in three steps for each of the three treatments: (1) The expected DPI was calculated based on the forecasted solar irradiance obtained from the Danish Metrological Institute (DMI, 2011), (2) if the set point for DPI was not reached by solar irradiance, the software calculated the most price-efficient timing of using supplemental light based on the electricity costs obtained from NordPool (Nord Pool Spot, 2011), (3) DynaLight then automatically transferred the resulting set points for timing and use of supplemental light to the climate computer (LCC Completa Senmatic, Søndersø, Denmark) and defined the light periods during the subsequent 24 h. The three treatments were named 300 NB, 450 NB* and 600 NB where NB refers to night breaks of light and the * refers to an additional light setting of continuous lighting with <5 $\mu mol\, m^{-2}\, s^{-1}$ at plant level from 2200 h to 1700 h by four incandescent lamps. An example of how the light periods were distributed in the four treatments during a three day period in autumn is shown in Fig. 1.