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Responses of two *Anthurium* cultivars to high daily integrals of diffuse light

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ABSTRACT

Heavy shading is commonly applied during production of pot-plants in order to avoid damage caused by high light intensities; usually the daily light integral (DLI) is limited to 5–8 mol m^{-2} d^{-1} photosynthetically active radiation (PAR). However, shading carries a production penalty as light is the driving force for photosynthesis. Diffuse glass has been developed to scatter the incident light in greenhouses. This study aims at investigating the effect of diffuse glass cover and high DLI under diffuse glass cover on the growth of pot-plants; furthermore, to systematically identify and quantify the yield components which are influenced by these treatments. Experiments were carried out with two *Anthurium andreanum* cultivars (Royal Champion and Pink Champion) in a conventional modern glasshouse compartment covered by clear glass with DLI limited to 7.5 mol m^{-2} d^{-1} (average realized DLI was 7.2 mol m^{-2} d^{-1}), and another two glasshouse compartments covered by diffuse glass with DLI limited to 7.5 (average realized DLI was 7.5 mol m^{-2} d^{-1}) and 10 mol m^{-2} d^{-1} (average realized DLI was 8.9 mol m^{-2} d^{-1}). Diffuse glass cover resulted in less variation of temporal photosynthetic photon flux density (PPFD) distribution compared with the clear glass cover. Under similar DLI conditions (DLI limited to 7.5 mol m^{-2} d^{-1}), diffuse glass cover stimulated dry mass production per unit intercepted PPFD (RUE) in 'Royal Champion' by 8%; whilst this stimulating effect did not occur in 'Pink Champion'. Under diffuse glass cover, biomass production was proportional to DLI in both cultivars (within the range 7.5–9 mol m^{-2} d^{-1}). Consequently higher DLI led to more flowers, leaves and stems. Furthermore, high DLI resulted in more compact plants without light damage in leaves or flowers in both cultivars. 'Pink Champion' produced more biomass than 'Royal Champion' in all treatments because of higher RUE which resulted from a more advantageous canopy architecture for light capture and more advantageous leaf photosynthetic properties. We conclude that less shading under diffuse glass cover not only stimulates plant growth but also improves plant ornamental quality (i.e. compactness).

1. Introduction

Light is the most important factor in determining plant growth. However, when excessive light energy is absorbed by the light harvesting antennae at a rate which surpasses the capacity for photochemical and non-photochemical energy dissipation, this may lead to photo-damage (Long et al., 1994). In the long term, this may result in discolouring of leaves or even necrosis in the most extreme case. Light damage occurs mostly as a result of prolonged exposure to excessive peaks in light intensity (Asada, 1999; Niyogi, 1999; Kasahara et al., 2002). Consequently, growers apply shading during summer cultivation of many greenhouse crops by closing a screen or having a white wash on the greenhouse cover in order to prevent damage under conditions of high light.

In greenhouses, the distribution of light over the different leaves of a canopy shows large variations. The greenhouse construction, equipment and overstory leaves cast shade, resulting in shade-spots and lightflecks, of which the position continuously changes depending on solar angle. Light damage may occur particularly in those lightflecks (Way and Pearcy, 2012). It has been shown that

Abbreviations: DLI, daily light integral; PPFD, photosynthetic photon flux density; PAR, photosynthetically active radiation; LAI, leaf area index; *K*, light extinction coefficient; SLA, specific leaf area; VPD, vapour pressure deficit; TDM, total dry mass; aFM, aboveground fresh mass; aDM, aboveground dry mass; aDMC, aboveground dry mass content (i.e. aboveground dry mass/fresh mass); aDMP, aboveground dry mass partitioning (i.e. aboveground dry mass/total dry mass); RUE, dry mass production per unit intercepted PPFD; I_i, cumulative intercepted PPFD; I_o, PPFD at top of plants; $I(L)$, PPFD at leaf area index L; $I(L)/I_o$, fraction of intercepted PPFD; Pn, net photosynthetic rate.

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diffuse light is more homogeneously distributed over the crop canopy than direct light (Farquhar and Roderick, 2003; Gu et al., 2002; Li et al., 2014; Mercado et al., 2009). Recently diffuse glass has become available that increases the diffuseness of light without affecting light transmission in the greenhouse (Baeza and López, 2012; Hemming et al., 2008). Li et al. (2014) observed that diffuse glass cover result in a more homogeneous light distribution not only in the vertical plane, but also in the horizontal plane within a tomato canopy, which compared with clear glass cover, lead to 10% higher yield (Dueck et al., 2012). Additionally, diffuse light also results in lower leaf or flower temperature and less photoinhibition (Kempkes et al., 2011; Li et al., 2014; Urban et al., 2012), because of less severe local peaks in light intensity. Considering these properties, we speculate that diffuse glass cover may help stimulate plant growth at higher daily light integral [DLI, mol m^{-2} d^{-1} photosynthetically active radiation (PAR)] without leading to light damage.

Increasing DLI increases plant growth and development (Marcelis et al., 2006; Poorter et al., 2013). Fausey et al. (2005) reported a linear relationship between the amount of light (5–20 mol m^{-2} d^{-1} PAR) and shoot dry mass in a number of greenhouse grown herbaceous perennial species. Similar findings were reported by Faust et al. (2005) in a number of bedding plants. Pot-plants are often grown under very low DLI conditions in commercial greenhouse production. For instance in the Netherlands growers limit the DLI in many pot-plants to 5–8 mol m^{-2} d^{-1}. However, it is clear that low DLI can carry a production penalty (Scuderi et al., 2012, 2013), since potential crop growth is positively related to the amount of light that can be captured. Pot-plants could grow faster when less shading was applied in combination with moderately high air humidity (Kromdijk et al., 2012). Furthermore, less shading could increase plant compactness as indicated by a higher ratio of aboveground dry mass to plant height with increasing DLI in a number of bedding plants (Faust et al., 2005). Therefore, increasing DLI can improve not only plant growth but also plant ornamental quality.

Yield component analysis has been valuable in many crop research programs (Higashide and Heuvelink, 2009; Jolliffe et al., 1990; Plénet et al., 2000). Lawlor (1995) suggested that plant growth and production is determined by component processes integrated over the canopy, e.g. dry mass production per unit intercepted photosynthetic photon flux density (PPFD) (RUE), leaf photosynthesis, canopy architecture, biomass allocation (e.g. shoot/root ratio). These components vary across species and environments (Barthelemy and Caraglio, 2007; Falster and Westoby, 2003; Sinclair and Muchow, 1999; Sultan, 2000; Sarlikioti et al., 2011b), resulting in differences in crop production.

The objective of this study was to investigate the effect of diffuse glass cover and high DLI under diffuse glass cover on the growth in pot-plants. It aims to systematically identify and quantify the yield components which are influenced by diffuse glass cover and high DLI. Our hypothesis is that high daily integral of diffuse light not only stimulates plant growth but also improves plant ornamental quality (i.e. more compact plants without light damage). To test this hypotheses, a study was conducted under diffuse glass cover with two levels of DLI. Two *Anthurium* cultivars (Pink Champion and Royal Champion) were used in this study; these two cultivars differed in light sensitivity based on grower's experience that 'Royal Champion' is more sensitive to light than 'Pink Champion'.

2. Materials and methods

2.1. Plant material and growth conditions

Two *Anthurium andreanum* cultivars (Pink Champion and Royal Champion, Anthura, Bleiswijk, The Netherlands) were grown in three Venlo-type glasshouse compartments of 144 m^2 (15 m × 9.6 m) with a gutter height of 5.5 m at Wageningen UR Greenhouse horticulture in Bleiswijk (TheNetherlands, 52°N, 4.5°E). The three compartments were covered by glass (Guardian Agro, Dudelange, Luxembourg) with 0% haze (clear glass; one compartment) and 71% haze (diffuse glass; two compartments). Haze is defined as the percentage of transmitted light that is scattered such that it deviates more than 1.5° from the direction of the incident beam. The hemispherical transmission of PPFD of the glass was 84% for both glass types. The haze factor and hemispherical transmission of the glass was measured in an optical sphere according to ASTM International (2007). The spectral properties of the two glass types are presented in Supplementary Fig. S1 and Table S1. The DLI was limited to 7.5 mol m^{-2} d^{-1} in the clear glass treatment, and to 7.5 and 10 mol m^{-2} d^{-1} in the two diffuse glass treatments. The DLI treatment of 10 mol m^{-2} d^{-1} under clear glass cover was not included in this experiment, because a similar treatment in an earlier experiment resulted in leaf damage (Van Noort et al., 2011). The DLI treatments were realized by controlling a white sunscreen (XLS 16 F Revolux, transmission of 37% and haze factor of 10%, LudvigSvensson, Kinna, Sweden) and blackout screen (XLS obscural Revolux A/B + B/B, LudvigSvensson, Kinna, Sweden) which were placed in the top of the greenhouse (below gutter height). The white sunscreen was fully closed in the low DLI compartments (7.5 mol m^{-2} d^{-1}) and 50% closed in the high DLI compartment (10 mol m^{-2} d^{-1}) when global outside radiation reached 250 W m^{-2}; it was fully closed in the high DLI compartment when global outside radiation reached 450 W m^{-2}. The blackout screen was closed when DLI reached the DLI limitation point in the afternoon in all compartments. Three quantum sensors (LI-190, LI-COR, USA) were installed in each of the greenhouse compartments to measure incident PPFD at 5 min intervals. Fogging systems were used to maintain high air humidity (80%). A standard horticultural computer (Hogendoorn-Economic, Hogendoorn, Vlaardingen, The Netherlands) was used to control the greenhouse temperature, air humidity, CO_2 concentration, as well as opening and closing of the screens.

Plants, propagated in vitro, were raised in a greenhouse by a nursery. When the first flowers had appeared, the plants were repotted and moved to the experimental greenhouses on 6 Apr 2012. The experiment ended on 28 Aug 2012. Plants were grown on potting soil (30% fine peat + 10% coarse peat + 43% coco peat + 10% bark + 7% perlite) in black plastic pots (12 cm diameter and 11 cm height) on cultivation tables (4 m by 1.8 m) with an automatic ebb/flood irrigation system. In each compartment, six cultivation tables were used and each table was equally divided into two parts for the cultivation of two cultivars. The outer two rows of each plot were considered as border plants. The starting plant density was 30 plants m^{-2}; this was reduced to 20 plants m^{-2} three weeks after the start of the experiment. After each destructive harvest, plants were moved to maintain the same plant density. During the growing season, average daily outside global radiation was 16 MJ m^{-2} d^{-1}. Inside the greenhouse the average day/night temperature was 25/21 °C; relative air humidity was 75/78%; average daytime CO_2 concentration was 754 μmol mol^{-1}; average realized DLI were 7.2 mol m^{-2} d^{-1} in the compartment of clear glass + low DLI, 7.5 mol m^{-2} d^{-1} in the compartment of diffuse glass + low DLI, and 8.9 mol m^{-2} d^{-1} in the compartment of diffuse glass + high DLI. An overview of DLI during the growing season in the three compartments is providedin Supplementary Fig. S2.

2.2. Plant measurements

Plants were destructively measured at 4, 10, 16, 18 and 21 weeks after the start of the experiment (at 18 weeks one extra