Interactive Effects of Duration of Long-day Period and Plant Density on External Quality of Cut Chrysanthemum

Susana M.P. Carvalho, Vrishali B. Dhonukshe and Ep Heuvelink
Wageningen University, Horticultural Production Chains Group
Marijkeweg 22, 6709 PG Wageningen
The Netherlands
E-mail: Susana.Carvalho@wur.nl

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Abstract

To quantify the effect of duration of long-day (LD) period and plant density on several chrysanthemum external quality aspects, a greenhouse experiment was conducted under summer conditions. *Chrysanthemum* 'Reagan Improved' was planted in May and grown under three durations (2, 9 and 16 days) of LD period combined with three plant densities (48, 64 and 80 plants m^{-2}). Plant height linearly increased with duration of LD period. Decreasing LD period from 16 to 2 days resulted in 25% shorter plants, but a marketable height was always reached (> 65 cm). Plant height showed an optimum response to plant density, however this effect was rather small (≤ 7%). Total number of flowers and flower buds per plant (NoF) increased with increased assimilate supply, measured as total plant fresh mass (TFM), whereas individual flower size (area and dry mass) was not affected. For example, plants that received 16 days of LD period and grown at 48 plants m^{-2} were the heaviest (91.5 g plant^{-1}) and obtained the highest NoF (28 flowers plant^{-1}). In contrast, 2 days of LD period and 80 plants m^{-2}, resulted in 57% lighter plants with 67% less flowers. A model to predict NoF was developed based on TFM (NoF= 0.353 TFM – 5.66; R^2= 0.93). It was concluded that a similar TFM could be obtained using several combinations of plant density and duration of LD, without affecting either NoF or individual flower size. A photosynthesis-driven crop growth model was validated and used to quantify this trade-off, when aiming at a certain TFM. It was shown that such trade-off is dependent on the planting date throughout the year.

INTRODUCTION

Cut chrysanthemum is a short-day (SD) plant, which is produced year-round in greenhouses. To permit the initiation of sufficient leaves so as to provide an adequate stem length, cuttings are kept vegetative under a long-day (LD) period for several days after planting. This is followed by a SD period that induces flower initiation. In winter LD treatment is achieved with supplementary light, while in summer blackout screens are used to create the SD conditions (Horridge et al., 1984). However, in Northern Europe the product quality varies greatly throughout the year (Heuvelink et al., 2001), as a consequence of the strong variation in the daily light integral (Lee et al., 2002b). Plant height, total number of flowers and flower buds per plant (NoF), flower size and flower position are major aspects of cut chrysanthemum external quality (Carvalho and Heuvelink, 2001). Because chrysanthemum is frequently sold in different weight classes, total plant fresh mass (TFM, g plant^{-1}) is also a critical aspect for its commercialisation. To achieve higher yield and to reduce these seasonal fluctuations in quality, cut chrysanthemum growers adjust plant density and duration of LD period according to the growing season (Spaargaren, 2002). For instance, in The Netherlands a crop planted in week 45, in a greenhouse without assimilation light, receives 32 LDs and is planted at 39 plants m^{-2}. In the same greenhouse a crop planted in week 10 receives only half of LDs and its plant density is increased to 60 plants m^{-2} (Spaargaren, 2002). To which extent the manipulation of these growing conditions affects external quality is still poorly studied.

As chrysanthemum is planted on a weekly basis (Spaargaren, 2002), the use of an explanatory model is a valuable tool to generalise this knowledge and as part of a decision support system (Challa, 1997).

The aim of the present work is to test the effect of high yield in a summer crop, resulting from short duration of LD period and a high plant density, on the main external quality aspects of cut chrysanthemum. This paper also aims to investigate possible interactive effects between duration of LD period and plant density on those quality aspects. A greenhouse experiment was conducted during summer combining three durations of LD period (2, 9 and 16 days) with three plant densities (48, 64 and 80 plants m^{-2}). An explanatory photosynthesis-driven crop growth model (Lee et al., 2002a) was validated and used to extrapolate this knowledge to other growing seasons. The trade-off between duration of LD period and plant density, when aiming at a certain TFM, is analysed for four different planting dates throughout the year.

MATERIALS AND METHODS

Plant Material and Growing Conditions

An experiment was carried out in one compartment (12.8 m × 12.0 m) of a multispan Venlo-type glasshouse at Wageningen University, The Netherlands (lat. 52°N). Block-rooted cuttings of *Chrysanthemum* 'Reagan Improved' (Fides Goldstock Breeding, Maasland, The Netherlands) were planted in three different planting dates (9, 16 and 23 May 2001), in eight parallel soil beds (1.125 m × 10.25 m).

Plants were grown under natural light conditions during the LD period (around 16h light per day for 2, 9 or 16 days). SD period was achieved by closing the blackout screen for 13 hours a day, from 25 May to harvest. No supplementary light was applied and temperature was set at 18.5°C day temperature and 19.5°C night temperature. Outside global radiation, greenhouse temperature and CO_2 concentration were automatically recorded each 5-min using a commercial computer system (Hoogendoorn, Vlaardingen, The Netherlands). Incident daily photosynthetic active radiation (PAR) was 18.2 mol $m^{-2}d^{-1}$. Mean 24 h greenhouse temperature was 22.2°C and mean CO_2 concentration, between 1000 and 1600 h, was 346 μmol mol^{-1}.

Destructive measurements were carried out at planting and harvesting dates. Initial stem and leaves fresh and dry mass (ventilated oven, 105°C for at least 15h) were measured on 20 plants, at each planting date. Harvest stage was defined as the moment when the first row of disc florets was in anthesis, in at least three inflorescences per plant. Since flower development rate differed slightly among treatments, harvest was spread over 6 days. Final plant height, number of leaves on the main stem, number of flowers, number of flower buds (>5mm) and flower position (15 cm from top) were recorded. TFM and total plant dry mass (TDM, g $plant^{-1}$) was also calculated. Individual flower dry mass and individual flower area (LI-COR Model 3100 Area Meter, USA) was determined for the fully opened flowers. Measurements were done on five plants per experimental plot, leaving two border rows on each side of the bed and between different treatments. No root measurements were performed.

Model Validation and Utilisation

A photosynthesis-driven crop growth model for cut chrysanthemum CHRYSIM1.0 (Lee et al., 2002a) was used to simulate total dry mass per m^2. Details on the model description and inputs of the model simulations are the same as for Lee et al. (2002a).

The model was validated using the greenhouse experiment referred above. Measured daily integral of outside global radiation, inside greenhouse temperature and CO_2 concentration were input to the model. A greenhouse transmissivity of 49% for diffuse radiation was measured and used as input. Observed initial stem and leaves dry mass per plant were also input to the model. Dry mass partitioning to the roots was assumed to be constant (10% of the TDM). For both model validation and utilisation leaf area index (LAI) and specific leaf area (SLA) were calculated as described by Lee et al. (2002a). SLA was adjusted to 80% of their values, based on the measured SLA.

Total dry mass per m^2 was simulated using the same combinations of LD period and plant density as in the greenhouse experiment. However, for each growing season, a fixed planting date was used instead of a fixed starting date for the SD period. An additional simulation per season was carried out using the reference commercial growing conditions for the corresponding planting date (DLV consultancy group, Wageningen, The Netherlands). Values for daily outside global radiation were taken from Breuer and Van de Braak (1989), representing average data for De Bilt (52°N, The Netherlands), but with natural variation. The use of supplementary assimilation light (49 $\mu mol\ m^{-2}\ s^{-1}$) was dependent on the global radiation (switch on at 200 and off at 300 $W\ m^{-2}$). Mean 24h greenhouse temperature varied between 19°C in winter and 21°C in summer. CO_2 concentration ranged from 400 $\mu mol\ mol^{-1}$ in summer up to 1000 $\mu mol\ mol^{-1}$ in winter. Day length was 20h for LD and 11.5h for SD period. Greenhouse transmissivity for diffuse radiation was assumed to be 70%, as it is more representative for commercial conditions. Duration of the response time, i.e. time from start of SD period to harvest, from plants grown under the reference commercial growing conditions was obtained from DLV consultancy group. For the non-reference growing conditions that information was adjusted based on experimental data. It was assumed that when LD period increased by 1 week, for the same plant density, the duration of SD period decreased by 1 day.

Total dry mass per m^{-2} was converted into total plant fresh mass by dividing by plant density and dry matter content. According to experimental data (Carvalho, unpublished), dry matter content varies with season (0.11-0.15) and with duration of LD period (increasing 1% when LD period increased by 1 week).

Statistical Design and Analysis

Nine treatments, resulting from the combination of three durations of LD period (2, 9 and 16 days) with three plant densities (48, 64 and 80 plants m^{-2}), were allocated to six beds and the two outer beds were used as border. The experimental set-up was a complete randomised block design with three replications. Each replication consisted of two consecutive soil beds. Analysis of variance and linear regression analysis was conducted and treatment effects were tested at 5 % probability level. Mean separation was done using Student's *t*-test ($P = 0.05$). The statistical software package Genstat 5 (IACR-Rothamsted, UK) was used.

RESULTS

Greenhouse Experiment

Plants that received 16 LDs and grown at 48 plants m^{-2} were the first ones to be harvested, revealing to have the shortest response time (53 days). In contrast, plants that received 2 LDs and grown at 80 plants m^{-2} had the longest response time (58 days). Nevertheless, the total cultivation period of the later was still 9 days shorter than the former.

Plant height showed a significant positive linear relationship ($P < 0.001$) with duration of LD period (Fig. 1A). Plants that received 16 days of LD period were 34% taller than plants that received 2 LDs. This positive effect on plant height was mainly a result of increased number of internodes (34% more internodes) and only marginally due to higher average internode length (6% longer internodes) (data not shown). Plant height increased with plant density up to an optimum of 72 plants m^{-2} ($P = 0.033$). However, at this density plants were only 7% taller than plants grown at 48 plants m^{-2} (Fig. 1B).

NoF was significantly ($P = 0.019$) influenced by the interaction between duration of LD period and plant density (Fig. 2A). In general, extending the duration of LD period and decreasing plant density resulted in more flowers per plant. However, the absolute effect of duration of LD period on NoF was larger at 48 plants m^{-2} compared to at higher plant densities. Furthermore, in plants that received 16 LDs there was a strong reduction in NoF when plant density increased from 48 to 64 plants m^{-2}, but a further increase up to

80 plants m^{-2} showed no significant effect on NoF. As a result of this interaction a similar NoF could be obtained with different combinations of these growing conditions. For example, a crop receiving16 LDs and growing at 80 plants m^{-2} or receiving 9 LDs and growing at 60 plants m^{-2} would both result in 17 flowers per plant, including flower buds.

The percentage of flowers in a bud stage was not significantly influenced by the duration of LD period (P = 0.271), but plant density showed a significant negative linear effect (P = 0.002). Thus, plants grown at 48 plants m^{-2} had 15% of their flowers in a bud stage, whereas plants grown at the highest plant density had 5% of flower buds only. Similarly, the percentage of flowers located at the first 15 cm from the top of the plant was not influenced by the number of LDs (P = 0.878). A significant positive linear relationship was, however, found between this flower percentage and plant density (P = 0.007). Plants grown at higher plant densities had their flowers more concentrated at the top of the plant (e.g. 78% top flowers, for 80 plants m^{-2}), whereas reducing plant density flowers became more distributed over the main stem (e.g. 69% top flowers, for 48 plants m^{-2}).

In contrast with the previous quality aspects, individual flower size was not affected by the duration of LD period (P = 0.145: flower area; P = 0.432: flower dry mass) nor by plant density (P = 0.995: flower area; P = 0.404: flower dry mass). Flower area and dry mass of the fully opened flowers was on average 29 ± 0.5 cm^2 $flower^{-1}$ and 0.21 ± 0.003 g $flower^{-1}$, respectively.

A significant interaction (P = 0.017) between duration of LD period and plant density was observed for TFM (Fig. 2B). The effect of this interaction on TFM was very close to the one observed for NoF, suggesting a positive relationship between these two variables (Fig. 2). Actually, when NoF was plotted against TFM a positive linear relationship was found (Fig. 3A). Plants that received 16 days of LD period and grown at 48 plants m^{-2} were the heaviest (91.5 g $plant^{-1}$) and obtained the highest NoF (28 flowers $plant^{-1}$). The opposite treatment combination, i.e. 2 days of LD period and 80 plants m^{-2}, resulted in plants with only 39.4 g and around 9 flowers per plant including buds.

Model Simulations

Simulated and measured total plant dry mass showed a good agreement for the nine studied combinations of LD period and plant density (Fig. 3B). The slope of the regression line, which relates simulated and measured TDM, was 1.08 indicating an average overestimation of 8%. However, this slope did not differ significantly from 1.0. Predicted dry mass varied between 96% and 139% of the measured value, where the highest overestimation was observed for combinations including 2 days of LD period. This was a result of a general overestimation of the LAI (leaf area index), which had a relatively stronger impact on a crop with low LAI.

Simulated TFM for the different seasons (Fig. 4) responded similarly to duration of LD period and plant density as TDM (not shown). Nevertheless, the lines were closer to each other for TFM as dry matter content is 1% higher when LD period increases by 1 week. Similarly to the greenhouse experiment higher number of LDs and lower plant density resulted in higher simulated TFM, being the LD period effect larger at low plant density (Fig. 4). This trend was always observed except for the autumn crops, where no effect of the duration of LD period on predicted TFM was found (Fig. 4C). Furthermore, the negative effect of plant density on simulated TFM was larger in spring and summer (Fig. 4A and B) compared to plants grown in autumn or winter (Fig. 4C and D). Therefore, although different combinations of number of LDs and plant density resulted in the same TFM, this trade-off was dependent on the season. For instance, a spring crop that received 2 LDs and was grown at 53 plants m^{-2} would result in a TFM of 86 g $plant^{-1}$, just like a crop that received 11 LDs and was grown at 65 plants m^{-2} (i.e., under the reference commercial growing conditions) (Fig. 4A). In contrast, in the autumn crops no possibilities of trade-off, for the simulated combinations, was possible (Fig. 4C). Simulations performed on the reference commercial growing conditions showed a rather constant TFM for the spring and summer crops. In autumn, but especially in the winter crops, a drastic reduction of predicted TFM was observed (Fig. 4).

DISCUSSION

Decreasing number of LDs, which resulted in a shorter cultivation period, or increasing plant density are possible ways to increase annual yield in cut chrysanthemum. This study clearly demonstrates that such changes can, however, strongly affect several external quality aspects. For example, plants grown under shorter duration of LD period or at higher plant density had fewer flowers per plant (Fig. 2A) and lower TFM (Fig. 2B). This negative effect of plant density on NoF is consistent with previous studies (Carvalho et al., 2002; Lee et al., 2002b). Nevertheless, it is interesting to realise that although plants grown at higher plant densities had fewer flowers, they had relatively more flowers with marketable value, i.e., lower percentage of flowers in a bud stage and higher percentage of flowers located at the top 15 cm of the plant.

In contrast to NoF, individual flower size was not affected by the duration of LD period or plant density. Apparently, the plant gives priority to invest the additional assimilates in more flowers rather than in a larger flower size. A similar behaviour was previously observed when assimilate supply was influenced by different combinations of light intensity and plant density (Carvalho et al., 2002).

As TFM shows a positive linear relationship with cumulative incident PAR per plant (Lee et al., 2002b) a higher simulated TFM was obtained during spring and summer compared to autumn and winter (Fig. 4). This relationship also explains why plants were heavier when the number of LDs increased, as this resulted in a longer cultivation period. In the September planting, however, the extension of the cultivation period only slightly contributed to the cumulative incident PAR, because this extension was during a period of low light intensity (Fig. 4C). Furthermore, the positive effect of LD duration on TFM was larger at low plant density (Fig. 2B; Fig. 4). This is due to a higher light interception per plant at low plant density. Consequently additional LDs represent per plant more additional light than at high plant density.

The negative effect of plant density on TFM was gradually smaller at higher densities. This can be explained by the fact that when plant density increases from 48 to 64 plants m^{-2} this represents a relative increase of 33%, whereas this is only 25% when plant density increases from 64 to 80 plants m^{-2}. The linear relationship between cumulative incident PAR and TFM also explains the larger negative effect of plant density on TFM during spring and summer than in autumn and winter.

From this work it can be concluded that a cut chrysanthemum grower can achieve a similar quality using different combinations of the two studied cultivation measures if an adequate trade-off between them is chosen. For instance, a crop grown during summer at 80 plants m^{-2} and receiving 16 LDs resulted in a TFM of 65 g and 17 flowers per plant, just as a crop grown at 58 plants m^{-2} and 9 days of LD period (Fig. 2 and 3A), without affecting individual flower size. However, this trade-off is dependent on the growing season and the strong positive effect of LD period on plant height must also be taken into account (Fig. 1A). This positive effect was mainly due to higher number of internodes as a result of later flower initiation. Therefore, the manipulation of LDs can be an effective method to control plant height. This is especially interesting in summer as an alternative method to the temperature manipulation (Hendriks and Ueber, 1995).

In this study it is shown that a crop simulation model is particularly useful as the trade-off between duration of LD period and plant density is strongly dependent on the planting date. The present biomass production model, combined with the module to predict flower number, can be used as a tool to define optimal combinations of these growth conditions throughout the year, when aiming at a certain chrysanthemum quality.

ACKNOWLEDGEMENTS

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Figures

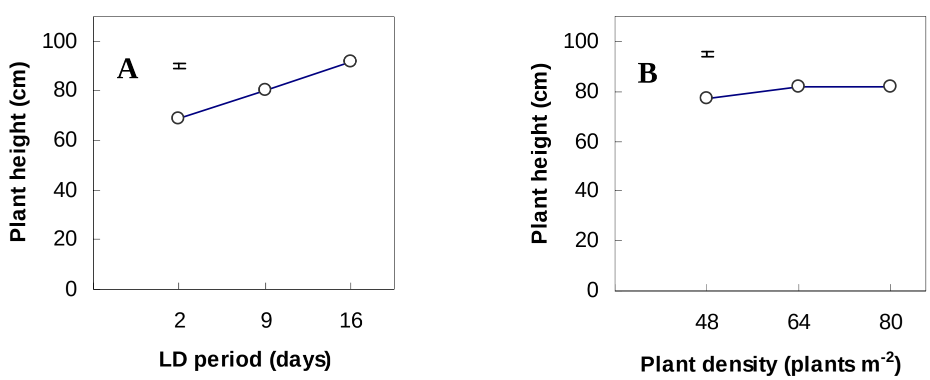

Fig. 1. Plant height as a function of duration of LD period (A) and plant density (B) at harvest of *Chrysanthemum* 'Reagan Improved'. Regression lines: A, y = 1.67x + 65.4; B, $y = -0.0093x^2 + 1.34x + 34.5$. Vertical bars indicate $LSD_{16,\ 0.05} = 2.5$.

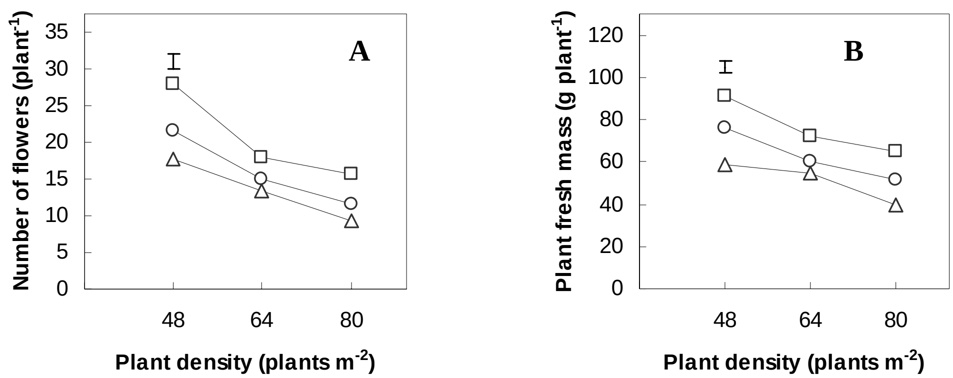

Fig. 2. Total number of flowers including buds per plant (A) and total plant fresh mass (B) as a function of duration of LD period (△ 2 days, ○ 9 days and □ 16 days) and plant density at harvest of *Chrysanthemum* 'Reagan Improved'. Vertical bars indicate LSD $_{16, 0.05}$ = 2.15 (A) and 6.04 (B).

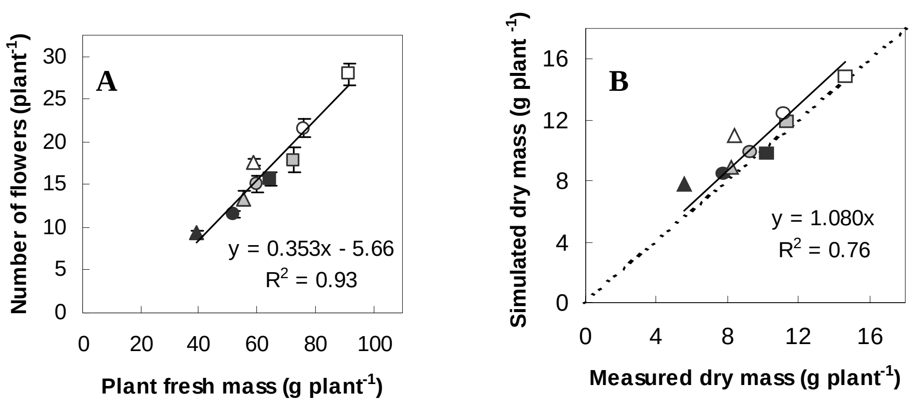

Fig. 3. Relationship between total number of flowers per plant, including buds, and total plant fresh mass (A); and simulated and measured total plant dry mass (B), at harvest of *Chrysanthemum* 'Reagan improved'. Each symbol represents the average from the combination of three durations of LD period (△, ▲, ▲ 2 days; ○, ●, ● 9 days and □, ■, ■ 16 days) and three plant densities (△, ○, □: 48 plants m^{-2}; ▲, ●, ■: 64 plants m^{-2} and ▲, ●, ■: 80 plants m^{-2}). Vertical bars indicate s.e.m. (n = 3) (A). Solid lines represent linear regression (A and B) and dashed line represents 1:1 relationship (B).

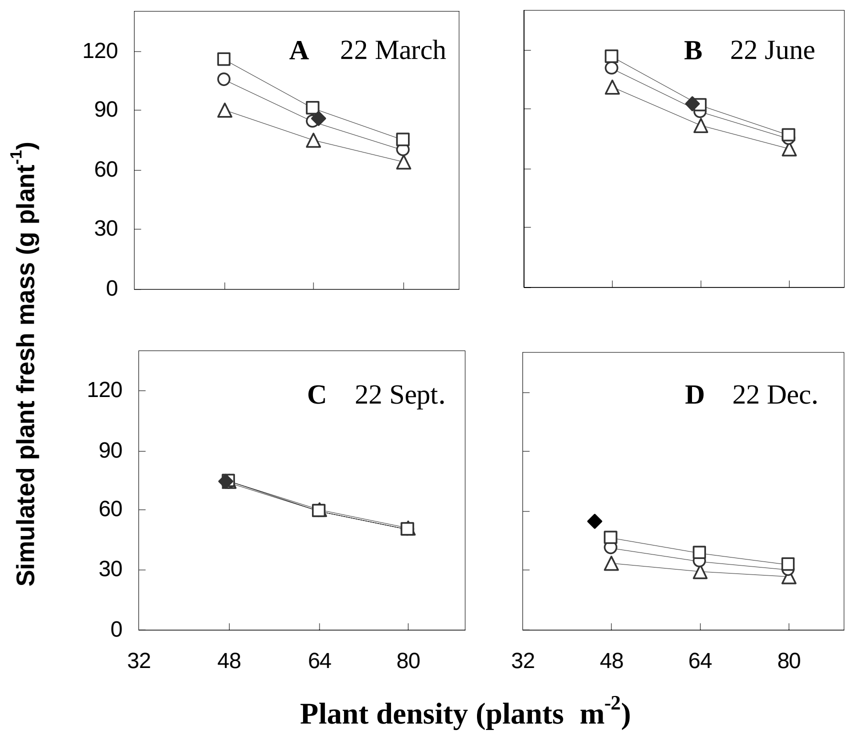

Fig. 4. Simulated total plant fresh mass, as a function of duration of LD period (△ 2 days, ○ 9 days and □ 16 days) and plant density at harvest of *Chrysanthemum* 'Reagan Improved', for four planting dates (A-D). Black diamonds represent simulations under reference commercial growing conditions: A, 11 days LD and 65 plants m^{-2} (1343 mol m^{-2}, cumulative incident PAR); B, 10 days LD and 62.5 plants m^{-2} (1449 mol m^{-2}); C, 15 days LD and 47.5 plants m^{-2} (649 mol m^{-2}); D, 19 days LD and 45 plants m^{-2} (469 mol m^{-2}).