Modelling Visual Product Quality in Cut Chrysanthemum

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ABSTRACT

Throughout the year, cut chrysanthemum growers aim at a constant product quality by varying plant density, duration of the long-day (LD) period and, more recently, by the use of supplementary assimilation light during periods of poor natural light conditions. Visual quality of cut chrysanthemum is mainly determined by plant mass (in relation to stem length), number of flowers per plant and flower size. For production in agreement with market demands at the lowest costs, models can be of great interest. We developed and validated an explanatory photosynthesis-driven crop growth model, that can predict influence of planting date, plant density, CO_2 concentration and supplementary assimilation light on visual quality of cut chrysanthemum. The model is presented and some validation results are given. It is shown how the model can be used to define acceptable plant densities throughout the year at different levels of assimilation light intensities or glasshouse light transmissivities. Also the trade-off between duration of the LD period and plant density, when aiming at a certain plant mass, is quantified using the model.

INTRODUCTION

Year-round production of greenhouse cut chrysanthemum, a short-day (SD) plant, is possible by controlling photoperiod using blackout screens and supplementary lights. Throughout the year, growers aim at a constant product quality in agreement with market demand (Langton et al., 1999). Visual quality of cut chrysanthemum is mainly determined by plant mass (in relation to stem length), number of flowers per plant and flower size. These quality attributes are influenced by both greenhouse climate and cultivation measures like plant density and the duration of the long-day (LD) period and by their interactions (Carvalho and Heuvelink, 2001).

Considering the complexity of cut chrysanthemum production, with its many controlling options and several product quality attributes, explanatory models seem to be a valuable tool to integrate knowledge and play a role in decision support systems (Challa, 1990). However, there are still few models for ornamental crops available (Marcelis et al., 1998) and these are mainly focused on growth and development rather than on product quality (Gary et al., 1998). Therefore, an explanatory photosynthesis-driven crop growth model for cut chrysanthemum, that includes visual product quality aspects is being developed (Carvalho and Heuvelink, 2001; Carvalho et al., 2001; Heuvelink et al., 2001; Lee et al., 2001). This paper presents the biomass production model combined with the module predicting the number of flowers per plant. Some examples of model validation and utilization are given.

MATERIALS AND METHODS

Model description

A photosynthesis-driven crop growth model for cut chrysanthemum, CHRYSIMv1.0 (Lee et al., 2001) was used to simulate dry mass production and plant fresh mass. Potential daily crop assimilation rate ($P_{gc,d}$) is computed by integration of leaf carbon assimilation rate over total crop leaf area and over the day. The maximum endogenous leaf photosynthetic capacity was assumed to be 1 mg CO_2 m^{-2} s^{-1} (Lee et al., 2001). Crop growth results from $P_{gc,d}$ minus maintenance respiration rate (dependent on temperature, relative crop growth rate and crop dry mass), multiplied by the conversion efficiency (carbohydrates to structural dry mass). Dry mass distribution is input to the model (model validation) or simulated based on crop developmental stage (model utilization). Functions describing dry mass partitioning in relation to crop developmental stage were based on destructive measurements in several experiments (Lee et al., 2001). Dry mass partitioning to the roots was assumed to be constant at 10%. Leaf area index is input to the model (model validation) or results from simulated leaf dry mass multiplied by specific leaf area (SLA). SLA is simulated as a function of day of the year. Strategies for supplementary assimilation light (intensity, minimum night hours, control based on radiation level outside) and blackout screens can be supplied as model input. Actual crop photosynthetic rates are calculated for each half-hour step and supplementary assimilation light was assumed to be 100% diffuse radiation.

The number of flowers per plant (NoF) was predicted from the simulated total plant dry mass (TDM) according to the following equation (Carvalho et al., 2001):

$$NoF = 2.08\ TDM - 4.98 \quad (1)$$

Model validation

An experiment was conducted in 4 compartments (12.8 m × 12.0 m) of a multispan Venlo-type glasshouse at Wageningen University, The Netherlands (lat. 52 ^{o}N). Rooted cuttings of chrysanthemum (*Dendranthema grandiflorum* Ramat. 'Reagan Improved'), were obtained from a commercial propagator (Fides, Maasland, The Netherlands), and planted on 12 January 2000 in eight parallel soil beds (each 1.13 m × 10.25 m) per compartment.

Plants were grown at day/night temperature setpoints of 16/17^{o}C or 20/21^{o}C, each applied to two of the greenhouse compartments. Within a compartment, two levels of supplementary lighting (control; incandescent lamps, 3.5 μmol m^{-2} s^{-1} PPFD (Photosynthetic Photon Flux Density) or assimilation light (high pressure sodium (HPS) lamps, SON-T Agro, Philips, The Netherlands, 48 μmol m^{-2} s^{-1} PPFD) and three plant densities (32, 48 or 64 plants m^{-2}) were applied. Temperature was applied as main factor, light level as split factor and randomised over the two halves inside each compartment and within a light level plant density was randomised (split-split-plot design).

LDs (19 h) were applied for 3 weeks followed by SDs (11 h; blackout screen and turn off lamps) until the end of the experiment. Lamps were on continuously during daytime. The experiment was finished when the plants had reached commercial maturity (about 75 days after planting).

Temperature, CO_2 concentration and outside global radiation were recorded every 5 min by a commercial computer system (Hoogendoorn, Vlaardingen, The Netherlands). Average daily outside global radiation was 4.8 MJ m^{-2} d^{-1}. Average 24-h greenhouse

temperature was 17.7 °C for the low temperature regime and 20.8 °C for the high temperature regime. Average CO_2 concentration between 10:00 - 16:00 was 415 μmol mol^{-1} in all compartments.

Destructive measurements were carried out every 3 to 10 days on the two center beds of the four beds from each compartment half. Samples were taken from 5 plants per experimental plot, excluding border plants (two rows on each side of a bed). Number of leaves (>10 mm) on the main stem, number of flowers (including buds), total leaf area (LI-COR Model 3100) and fresh and dry (105 °C for 14 h in a ventilated oven) mass of leaves (including petioles), stems and flowers were measured. No measurements on roots were conducted.

Measured hourly averages of outside global radiation and inside greenhouse temperature and CO_2 concentration were input to the model. A greenhouse transmissivity of 63% for diffuse radiation was estimated, based on measurements in a similar greenhouse compartment (Heuvelink et al., 1995). Observed leaf area index and dry mass partitioning to leaves, stems and flowers were also input to the model.

Model utilization

CHRYSIMv1.0 was used to determine acceptable plant densities for cut chrysanthemum throughout the year at increased supplementary light intensities or in a glasshouse with an improved light transmissivity. Details on the model input and settings were the same as for Lee et al. (2001).

Total dry mass production at reference plant densities (43-65 plants m^{-2}) and length of the LD and SD period under the reference supplementary assimilation light intensity of 49 μmol m^{-2} s^{-1} was simulated for each week. These total dry mass productions were converted into plant fresh mass by dividing by plant density and dry matter content (0.11-0.14 depending on season). Simulated plant fresh mass at 49 μmol m^{-2} s^{-1} was used as reference plant fresh mass. As a linear relation between final plant dry mass and number of flowers is used in the model, aiming for a reference plant mass means also aiming for a reference number of flowers per plant. Dry mass production at a supplementary assimilation light intensity of 104 μmol m^{-2} s^{-1} or a glasshouse light transmissivity of 77% instead of the default value (70%) was simulated without changing LD and SD period in each week. The acceptable plant density was then calculated as the ratio between plant fresh mass and reference plant fresh mass multiplied by the reference density.

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. Strategy for using assimilation lamps was dependent on global radiation (switch on at 200 and off at 300 W m^{-2}). Crop management, i.e. plant densities (43-65 plants m^{-2}), duration of the LD period (10-20 days) and total cultivation period (64-82 days) for weekly plantings at a supplementary assimilation light level of 49 μmol m^{-2} s^{-1} was obtained from DLV consultancy group (Wageningen, The Netherlands). Daylength was 20 h (LD) and 11.5 h (SD).

Effect of plant density (32, 48 or 64 plants m^{-2}), combined with duration of the LD period (0, 7, 14 or 21 days), on plant fresh mass was simulated for a crop planted in week 21 (day 150), with an initial plant dry mass of 0.34 g. Daily outside global radiation was taken from Breuer and Van de Braak (1989). No supplementary assimilation light was applied, greenhouse air temperature was 21°C and CO_2 concentration was 400 μmol mol^{-1}.

During the LD period natural daylength was about 15 h and daylength during the SD period (56 days) was 11.5 h. A dry matter content in the final plant mass of 0.135 was assumed.

RESULTS

The model predicted crop growth with or without supplementary assimilation light reasonably well (Fig. 1). The simulated growth curve followed the measured crop dry mass closely, although in the last weeks of the cultivation crop growth rate was slightly underestimated under supplementary assimilation light. For the control treatment, crop growth rate was slightly overestimated in the middle of the cultivation period. Simulated and measured plant fresh mass showed good agreement for all 12

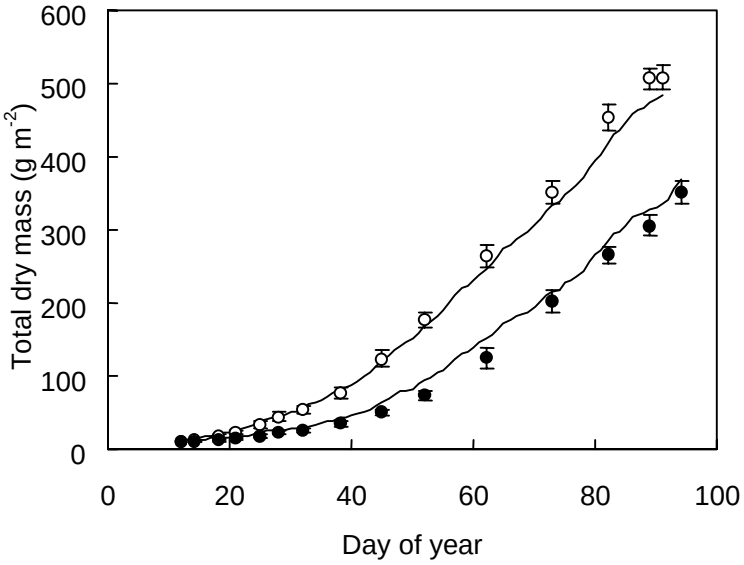

Fig. 1. Simulated (—) and measured (● control, ○ supplementary assimilation light) dry mass as a function of day of the year, averaged over three plant densities (32, 48 and 64 plants m^{-2}) for the 16/17°C day/night temperature regime. Vertical bars indicate standard error of mean when larger than symbols.

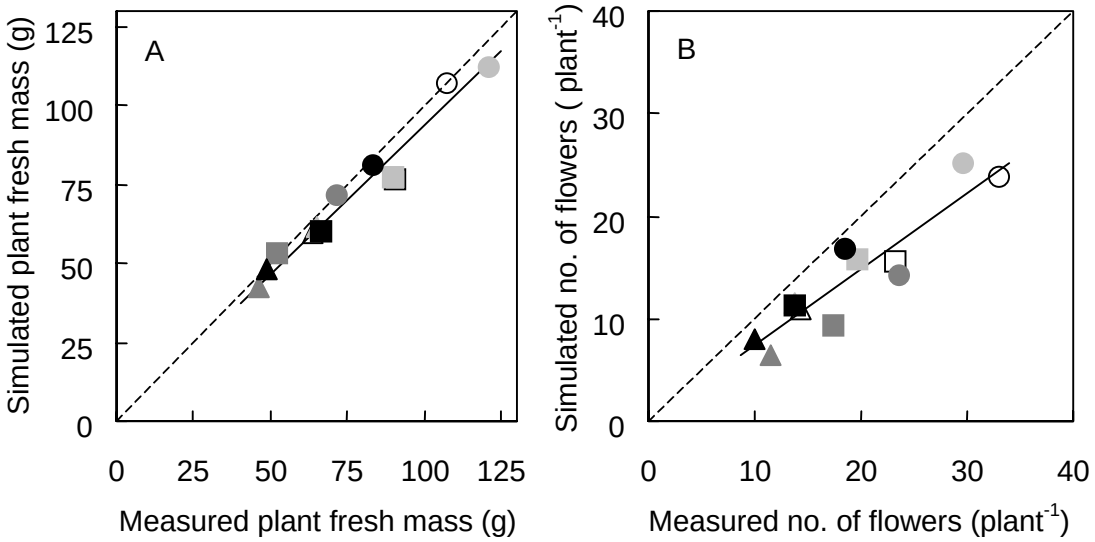

Fig. 2. Simulated plant fresh mass (A) and number of flowers (B) plotted against measured values. Symbols indicate different treatments: open symbols for HPS at 20/21°C day/night temperature regime, light gray for HPS at 16/17°C, dark gray for control at 20/21°C, black for control at 16/17°C. Plant density is indicated by circles (32), squares (48) and triangles (64 plants m^{-2}). Solid line represents linear regression y=0.939x (A; r^2=0.96) and y=0.743x (B; r^2=0.85).

combinations of temperatures, supplementary assimilation light intensities and densities (Fig. 2A). The intercept of the regression line relating simulated to measured plant fresh mass was not significantly different from zero and the slope of the regression was 0.94, indicating an average underestimation by 6%. Predicted fresh mass was between 85% and 102% of the measured value.

Based on the dry mass predictions underlying Fig. 2A (represented fresh mass were all based on a dry matter content of 0.13), number of flowers per plant was estimated. A systematic underestimation was observed (Fig. 2B), which was larger for treatments with high flower numbers. The intercept of the regression line relating simulated to measured number of flowers was not significantly different from zero and the slope of the regression was 0.74, representing an average underestimation by 26%.

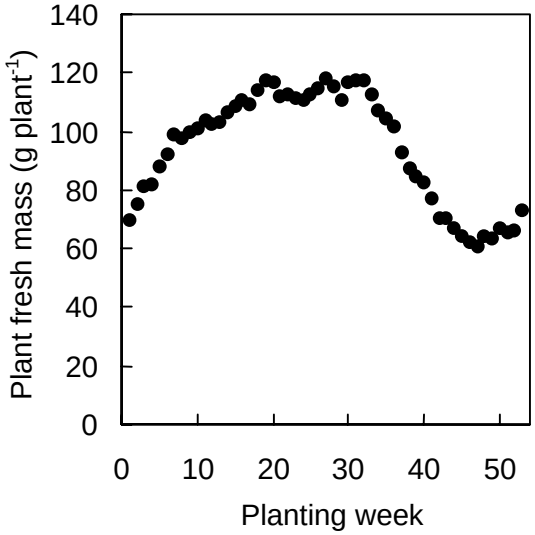

Fig. 3. Simulated plant fresh mass at reference plant density and at 49 μmol m^{-2} s^{-1} supplementary light.

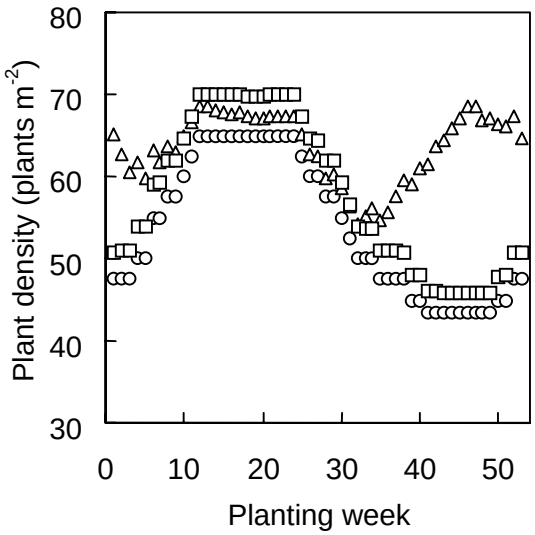

Fig. 4. Reference plant density for a glass-house with a transmissivity of 70% and for 49 μmol m^{-2} s^{-1} supplementary assimilation light (○) and acceptable plant densities calculated for 104 μmol m^{-2} s^{-1} assimilation light (Δ), or a glasshouse with an improved transmissivity of 77% (□).

Aiming for a reference plant fresh mass throughout the season as shown in Fig. 3, CHRYSIMv1.0 was used to predict acceptable plant densities under improved light conditions. Increased supplementary assimilation light intensity substantially increased acceptable plant densities in winter, whereas in summer the effect was only small (Fig. 4). For example, when planted in week 45, a crop grown at 43 plants m^{-2} with 49 μmol m^{-2} s^{-1} supplementary light resulted in a plant fresh mass of 64 g, just as a crop grown at 67 plants m^{-2} with 104 μmol m^{-2} s^{-1} (Fig. 4). Yearly production increased from 248 to 292 plants m^{-2} $year^{-1}$, respectively. A glasshouse with 10% improved light transmissivity (77% instead of 70%) resulted in increased acceptable plant densities for both summer and winter, although the absolute increase was larger in summer (Fig. 4). Annual production increased with 7.3%.

Simulating plant fresh mass for chrysanthemum crops varying in plant density and duration of the LD period revealed a strong interaction between both factors (Fig. 5). A lower density and an increase in number of LDs resulted in an increase in plant fresh mass. However, at low density the absolute mass differences between the LD treatments

where much larger than at high density. The same tendencies were observed for the predicted number of flowers per stem (not shown). Different combinations of plant density and the duration of the LD period could result in the same plant fresh mass. For example, a crop grown at 64 plants per m^2 and 21 days LD period resulted in a plant mass of 129 g, just as a crop grown at 50 plants per m^2 and 7 days LD period (Fig. 5).

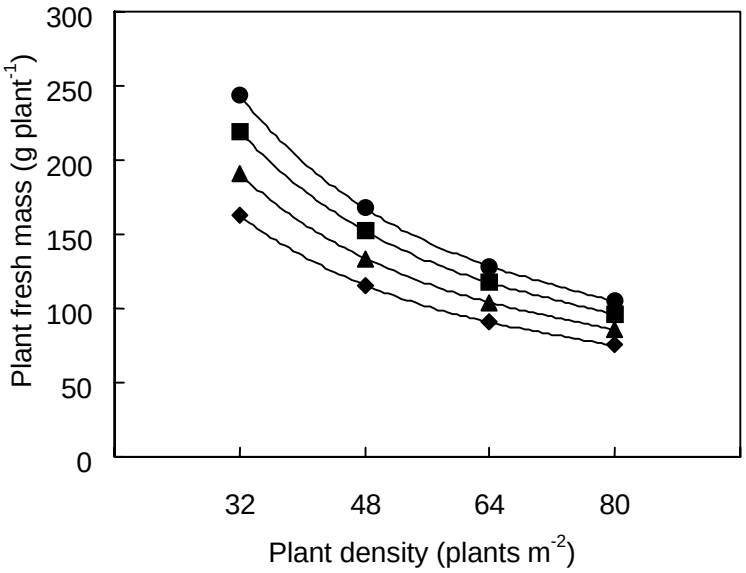

Fig. 5. Simulated plant fresh mass as influenced by plant density and duration of the LD period (♦ 0, ▲ 7, ■ 14 or ● 21 days). Details in Materials and Methods.

DISCUSSION

Before a model can be used and one can have confidence in its predictions, a thorough validation on datasets not used for calibration of the model is needed (Van Keulen, 1975). Fig. 2 shows a good agreement between measured and simulated plant fresh mass under a range of conditions. This, together with the validation of the dynamic growth behaviour (Fig. 1 and Lee et al., unpublished data) gives confidence in the growth predictions by the model.

Although a good correlation between measured and simulated number of flowers per plant was observed, the number of flowers was systematically underestimated (Fig. 2). This indicates that a close relation between plant dry mass and number of flowers existed, but this relationship was not the same as equation 1. A possible reason can be that the relationship between plant dry mass and number of flowers depends on the season. Our experiment was conducted in the beginning of the year, whereas equation 1 is based on a shading experiment in summer. Certainly, more research on the validity of predicting flower number from total plant dry mass is needed.

Once a model has been validated, it can be used for predictions under variable model input. For example, Fig. 4 shows results for 53 × 3 = 159 chrysanthemum cultivations, each "grown" for 64-82 days. For winter crops a substantial increase in plant density was possible under higher supplementary light intensities, without affecting plant fresh mass, whereas in summer acceptable plant densities were hardly affected by supplementary light intensities (Fig. 4). This resulted from the fact that in winter crops supplementary light substantially contributed to the total light integral and increased crop photosynthesis and biomass production, which has also been observed by Eng et al. (1985) and Heuvelink et al. (2001). In summer crops supplementary light hardly contributed to the total light integral, as natural light integral was already very high and the number of hours the lamps were on was low (twice as long a natural daylength and five times higher average natural light intensities as in winter). It seems unexpected that 104 μmol m^{-2} s^{-1} supplementary light in a winter crop results in acceptable plant densities

which are even higher than in summer. However, it should not be forgotten that the reference plant mass was much lower in winter than in summer (Fig. 3).

An increased glasshouse transmissivity increased acceptable plant densities more in summer than in winter (Fig. 4). This resulted from the much higher daily light integral in summer compared to winter. As cumulative intercepted light shows a linear relationship with cumulative dry mass production (Heuvelink et al., 2001), dry mass production increased more in summer. Although glasshouse transmissivity increased by 10%, annual production increased by only 7%. This is at least partly the result of winter cultivations, which receive relatively large amounts of supplementary assimilation light and this light was not also increased by 10% but remained the same.

The interaction between plant density and the duration of the LD period (Fig. 5) can be explained, as an increased LD period means increased light interception by the crop. Cumulative intercepted light shows a linear relationship with cumulative dry mass production (Heuvelink et al., 2001) and thus for all plant densities a similar total dry mass increase, with increased LD period, is expected. Hence, at low plant density this means a larger plant dry mass increase (divided over less plants) than at high plant density. Despite the fact that less LDs combined with a reduced plant density may result in an acceptable plant mass (Fig. 5), it is not always practical as plants may become too short. Furthermore, if the number of LDs is increased too much, a flower will be initiated in the LD already, which will abort and this results in a poor quality product.

The present model is, as far as we know, one of the first explanatory models integrating crop growth and visual product quality in an ornamental crop. The applicability of the model will be further improved by adding a module for predicting stem length. Recently, more knowledge on internal quality (vase life) of cut chrysanthemum has been obtained (Van Meeteren et al., 2001) which would also be a valuable addition to the model.

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