A Conceptual Dynamic Model for External Quality in Kalanchoe

B. Eveleens-Clark[1], S.M.P. Carvalho[1,2] and E. Heuvelink[2]
[1]Applied Plant Research
Glasshouse Horticulture
Linneauslaan 2a
1431 JV Aalsmeer
The Netherlands

[2]Wageningen University
Horticultural Production Chains Group
Marijkeweg 22
6709 PG Wageningen
The Netherlands

Keywords: *Kalanchoe blossfeldiana*, modelling, number of flower heads, plant density, plant height, temperature, timing of spacing, visual quality

Abstract

Modelling quality in pot plants is still a weak feature in crop modelling research. This work aims at building a conceptual dynamic model for external quality (plant height and number of flower heads) in *Kalanchoe blossfeldiana*. Four experiments were conducted to quantify the effects of temperature and spacing schedules at two different planting dates. Five constant temperatures (18, 20, 22, 24 and 26°C) and nine spacing schedules, resulting from combinations of spacing at a given leaf area index (LAI: 1.6, 2, 3, 4 and 4.4) into a final plant density (31.1, 34.6, 43.4, 52.0 and 55.6 plants m^{-2}) were studied. Stem length was modelled as the number of internodes (same as number of leaf pairs) times the average internode length. Plant height results from the stem length plus the uppermost pedicel length. The spacing schedules did not affect plant height, but total aerial dry mass (TDM, g plant^{-1}), leaf area and number of flower heads were increased at earlier and wider spacing. In contrast, temperature had a significant effect on the average internode length (internode elongation rate linearly increased with temperature) and on the generative length (optimum response to temperature). However, internode appearance rate was not affected by temperature. Number of flower heads showed a positive linear relationship with TDM. Therefore, by simulating TDM the number of flower heads can be predicted. TDM was simulated based on the intercepted photosynthetic active radiation and light use efficiency. The reaction time showed a quadratic response to temperature, with a maximum rate of progress to flower at 23°C (10 days delay at 18°C). These modules need to be validated to form the basis of a year-round decision support system for Kalanchoe.

INTRODUCTION

In The Netherlands *Kalanchoe blossfeldiana* is produced year-round and in 2002 it represented the first flowering pot plant in terms of area (44.5 ha) (CBS, 2002) and the second in terms of trade value in the Dutch auctions (37 million Euro), after Phalaenopsis (VBN, 2002). Since the production of pot plants is strongly influenced by market requirements a well-defined product must be available at a specific time. Therefore, to increase client satisfaction kalanchoe growers aim at increasing certainty of the delivery date and maintaining quality throughout the year (compact plants, high number of flower heads, and one to three open flowers at harvest). Although this crop is largely mechanised, at present the tools for an adequate planning and quality control are insufficient and need to be improved to face market demands. Image processing is a suitable tool for recording objective plant features, and this was successfully applied to monitor plant height in *Ficus benjamina* (Dijkshoorn-Dekker, 2002). The use of a growth and quality model, alongside the existing automatic grading and measuring systems for kalanchoe, would provide growers with a valuable tool for decision support. The model should be preferably dynamic, to give the possibility to predict at any moment of the cultivation whether the delivery date and quality targets can be achieved. Such a dynamic model would allow different batches to be subjected to different treatments to meet the final quality requirements.

Proc. Int'l. WS on Models Plant Growth &
Contr. Prod. Qual. in Hort. Prod.
Eds. M. Fink and C. Feller
Acta Hort. 654, ISHS 2004

Modelling quality in pot plants is still a weak feature in crop modelling research (Marcelis et al., 1998). Moreover, for *Kalanchoe blossfeldiana* only very limited information is available on the effects of the growth conditions on external (visual) quality aspects. For instance, a strong effect of light on growth and a significant effect of temperature on both time to flower and dry mass partitioning into the flowers was reported for kalanchoe (Buwalda et al., 2000). Nevertheless, no information is available on several important external quality aspects, such as plant height and number of flower heads.

The overall aim of this work is to build a dynamic model for time to flower and external quality in *Kalanchoe blossfeldiana*. This paper focuses at the development of conceptual dynamic modules to predict plant height and number of flower heads. The effects of temperature and spacing schedules were investigated for different planting dates and this experimental data set was used as the basis for parameter selection and estimation.

MATERIALS AND METHODS

Experimental Set-up

To quantify the effects of temperature and spacing schedules at two different planting dates four experiments were conducted in a multispan Venlo-type glasshouse (Aalsmeer, The Netherlands, lat. 52°N) (Table 1). Unrooted cuttings, with three or four leaf pairs, of *Kalanchoe blossfeldiana* 'Tenorio' (Fides Goldstock Breeding, Maasland, The Netherlands) were planted in 10.5 cm pots filled with a peat-based commercial potting compost (PG mix, EGO, Bleiswijk, The Netherlands) and placed at a density of 104 plants m^{-2}. In Exp. 1 and 2 plants were distributed among five compartments (4.5 m × 3.3 m) and were grown at a constant daily temperature (18, 20, 22, 24 and 26°C), after rooting for around two weeks under 20°C. Temperature was controlled by heating and mechanical cooling. Exp. 3 and 4 were conducted in one glasshouse (25 m × 12 m). Plants were initially subjected to long-day conditions (LD, minimal 13 hours of light) followed by a short-day period up to harvest (SD, maximal 10 hours of light). The LD period ended when seven visible leaf pairs had been reached (Table 1). In Exp. 1, 2 and 4 the natural photoperiod was extended using supplementary light (SL-R lamps, approx. 10 $\mu mol\ m^{-2}\ s^{-1}$). Blackout screens were used in Exp. 3 and 4 to promote the SD conditions. In the temperature experiments density was reduced to 43 plants m^{-2} when the leaf area index (LAI) reached 3, and for a second time to 30 plants m^{-2} when the LAI again reached 3. In Exp. 3 and 4 plants were spaced out at a pre-set LAI to a final plant density, according to correspondent treatment (LAI/plants m^{-2}): 1.6/43.4; 2/34.6; 2/52.0; 3/31.1; 3/43.4 (control); 3/55.6; 4/34.6; 4/52; 4.4/43.4. Plants were irrigated as required (EC = 1.7 or 2.2 dS m^{-1}, respectively during rooting and further cultivation period), manually (Exp. 1 and 2), or using an ebb/flood system (Exp. 3 and 4). No growth regulators were applied to the plants.

Plant height and number of leaf pairs on the main shoot were recorded weekly in all experiments. In Exp. 1 periodic destructive measurements were carried out to determine total aerial dry mass (TDM, g $plant^{-1}$) and leaf area (LA), in order to calculate light use efficiency (LUE, g MJ^{-1}). At final harvest, fresh and dry weights of the stems, leaves and flowers were measured (except for stem weights in Exp. 4). Total LA and final number of flower heads (i.e. flowering side shoots plus top flower) were recorded in all the experiments, and the response time was only registered in Exp. 2. No root measurements were made.

Temperature (Table 1) and CO_2 concentration were automatically recorded. The CO_2 levels averaged 400 ppm in all experiments. Daily outside global radiation was obtained from a meteorological station (Table 1). Daily incident photosynthetic active radiation (PAR) was calculated using a glasshouse transmissivity of 0.45 (Exp. 1 and 2) or 0.65 (Exp. 3 and 4). The loss of radiation blacked out during the SD was taken into account for when calculating the daily incident PAR.

The simulation software package Powersim 'Studio Academic 2003' (Powersim Inc., Bergen, Norway) was used to implement the models.

Statistical Design and Analysis

A complete randomised design with ten replications was applied to Exp. 1 and 2. Exp. 3 and 4 were set-up using a central composite design (Montgomery, 2001), with five replications.

RESULTS

Modelling Plant Height

A dynamic module was developed to predict plant height in time, based on the experimental data set (Fig. 1). Plant height was divided into its main components: vegetative length (i.e. stem length) and generative length (i.e. length of the uppermost pedicel). Since the spacing schedules did not influence significantly any of these plant height components (data not shown), in none of the studied growth seasons (autumn and summer), the timing of spacing the plants as well as the plant density were not included into the module. In contrast temperature showed a significant effect on both vegetative and generative length. Vegetative length was modelled as the number of internodes (same as number of leaf pairs) times the average internode length. As kalanchoe is a SD flowering plant, with a determinate growth pattern, the number of internodes can only be formed during the LD period prior to the flower initiation. Nevertheless, not all the formed internodes are visible during the LD period. Thus, based on the observations three additional internodes were added into the model since they became visible during the SD period only. The internode appearance rate (IAR) was not affected by temperature, resulting in 0.09 internodes per each LD. A higher value of 0.13 was, however, observed in the summer experiment (Exp. 3). Internode elongation rate (IER, mm day^{-1}) linearly increased with temperature whereas the generative length showed an optimum response to temperature (data not shown). To model dynamically the generative length information is needed on the start of generative length growth and on the generative elongation rate, which we assume to be temperature dependent (Fig. 1).

Modelling Number of Flower Heads

The number of flower heads increased linearly with TDM (Fig. 2). Therefore, by simulating TDM the number of flower heads can be further estimated using such relationship. In Fig. 3 an explanatory module is presented to predict TDM based on the intercepted PAR and on the LUE. Fraction of intercepted PAR can be modelled dynamically as a function of LA, which is calculated as the product of the TDM with the leaf mass ratio (LMR, 0.65; dry matter partitioning into the leaves) and with the specific leaf area (SLA, 200 cm^2 g^{-1}).

Periodic measurements of dry mass production showed a positive linear relationship with the cumulative fraction of intercepted PAR for plants grown at different temperatures (Fig. 4A). However, the slope of the regression line, which represents the LUE, varied with temperature. Increasing temperature resulted in a quadratic reduction of the LUE (Fig. 4B), which reflects the observed negative effect of temperature on the TDM and consequently on the number of flower heads.

Time to Flower

Time to flower is the sum of the duration of the LD period plus the reaction time. The latter was calculated as the number of days from start of SD period till sepals of the main bud start to open showing the colour of the petals. The reaction time had a quadratic response to temperature, with a maximum rate of progress to flower at 23°C, which represented a 10 days delay as compared to plants grown at 18°C (Reaction time = $0.45Temp^2 - 20.64Temp + 317.8$; $R^2 = 0.88$).

DISCUSSION

The results presented in this paper clearly show that temperature is a key parameter to model plant height, whereas the timing of spacing the plants and their final density were found to be unimportant inputs into the height module. Plant height showed a positive response to temperature only due to an increase in the average internode length and the generative (pedicel) length. IAR was unaffected by temperature but a seasonal effect was observed. Both in autumn and winter 0.9 internodes were formed every 10 long-days but this increased to 1.3 internodes in the summer experiment, leading to the conclusion that light has an effect on IAR. However, since the IAR is rather low and the duration of LD period in kalanchoe production is rather short (excluding the rooting period, Table 1), these two parameters have a minor impact in the final plant height. Therefore, it is of minor importance to accurately parameterise the IAR as a function of the season. The observed minor effect of plant density on plant height as well as the positive linear relationship between number of flowers and TDM were previously described for cut chrysanthemum (Carvalho and Heuvelink, 2003). The similarities between these two short-day plants suggest that these findings might be of a rather general nature.

The conceptual modules presented in this paper need some refinement and validation to form the basis for a year-round decision support system (DSS) for the external quality of kalanchoe. Such a DSS consists of three parts: objective plant measurements using image processing, grading on the basis of the measured plant characteristics and the application of a crop model to predict and control crop quality according to previously defined criteria. The use of image processing as a non-destructive technique to measure, for instance, the LA in time is a very interesting tool to supply information to the current model. A validation experiment will be conducted to study in detail possible interactions between light and temperature. For instance, the possibility of a reduction of the LUE at high light intensities (Lee et al., 2002), needs to be investigated, as this will have a strong influence on the predicted TDM. A time to flower ‘module’ also needs to be incorporated into the TDM module to work as a ‘stop function’ that should dictate when the crop is ready for selling. According to Buwalda et al. (2000), time to flower is influenced by the interaction between temperature and light and, therefore, such relationship must be accurately quantified.

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Tables

Table 1. General information on four greenhouse experiments using *Kalanchoe blossfeldiana* 'Tenorio'. Dates are expressed as day of the year (day 1 = 1st January). Abbreviations: LD = long-day; PAR = photosynthetic active radiation; SD = short-day.

Exp	Planting date	Harvest date	Duration of LD[x] (d)	Temperature[y] (ºC)	Outside global radiation[y] ($mol\ m^{-2}d^{-1}$)	Incident PAR[z] ($mol\ m^{-2}d^{-1}$)
1	256 (week 37)	21	42	17.9, 19.9, 21.9, 23.8, 25.8	17.9	6.8/2.3/3.8
2	328 (week 47)	94	57	18.2, 20.1, 22.0, 24.0, 25.9	17.2	1.8/5.0/3.6
3	130 (week 19)	234	37	22.8	78.3	18.8/15.6/16.8
4	285 (week 41)	43	39	20.1	14.1	5.2/4.0/4.3

[x] Including rooting period (≈ 2 weeks)
[y] Averaged over the whole cultivation period
[z] Averaged over: LD period/ SD period/ whole cultivation period

Figures

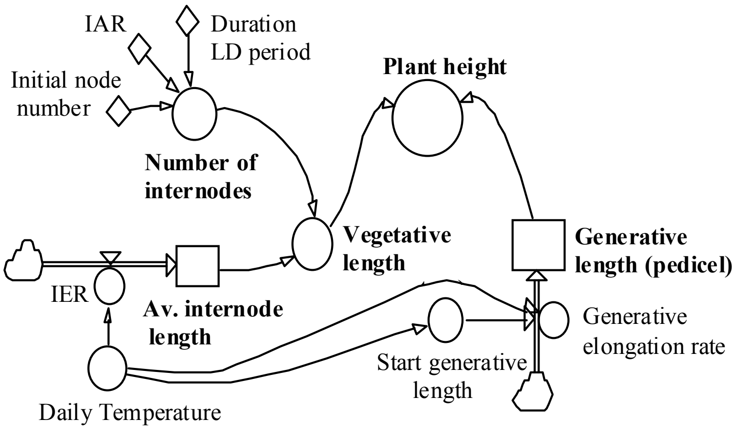

Fig. 1. Schematic presentation of a dynamic module for plant height in Kalanchoe. Boxes represent state variables, circles represent parameters and valves represent rate variables. Abbreviations: IAR = internode appearance rate; IER = internode elongation rate; LD = long-day.

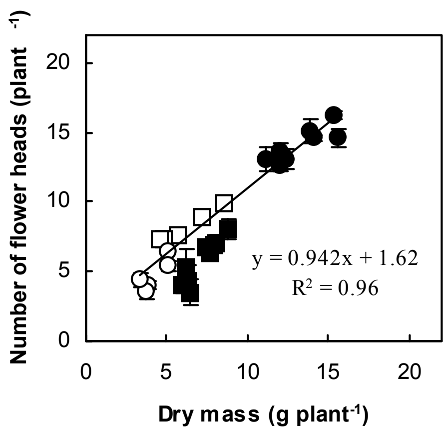

Fig. 2. Relationship between number of flower heads and total aerial dry mass per plant at harvest of *Kalanchoe blossfeldiana* 'Tenorio'. Symbols represent: ○ Exp. 1, Y Exp. 2, ● Exp. 3, ▪ Exp. 4 (estimated values). Line represents linear regression on all the data except Exp. 4. Vertical bars indicate s.e.m. when larger than symbols.

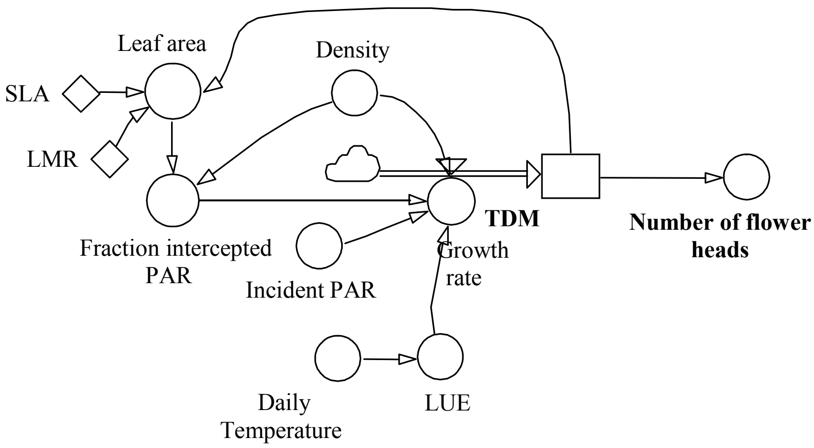

Fig. 3. Schematic presentation of a dynamic module for total aerial dry mass per plant (TDM) in Kalanchoe. Boxes represent state variables, circles represent parameters and valves represent rate variables. Abbreviations: LUE = light use efficiency; LMR = leaf mass ratio; PAR = photosynthetic active radiation; SLA = specific leaf area.

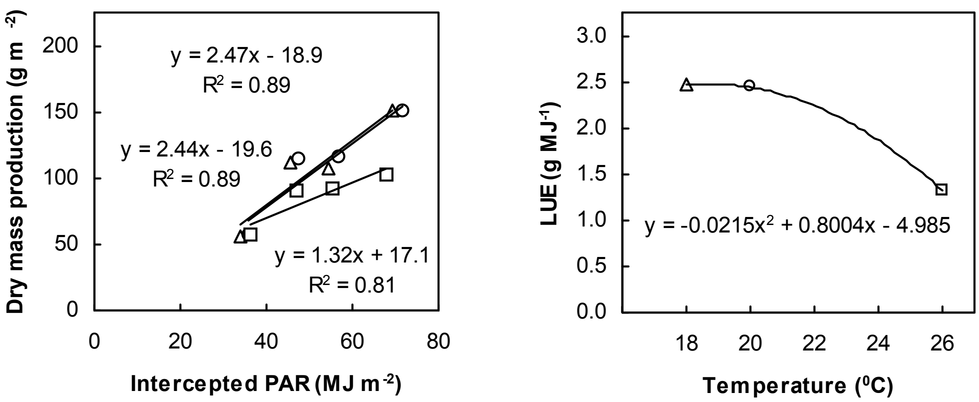

Fig. 4. Relationship between dry mass production and cumulative fraction of intercepted PAR (A) and light use efficiency, LUE (B) for *Kalanchoe blossfeldiana* 'Tenorio' grown at △ 18 °C, ○ 20 °C and Y 26 °C (Exp. 1).