Potential growing model for the standard carnation cv. Delphi

Modelo del crecimiento potencial de clavel estándar cv. Delphi

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ABSTRACT

The cut flower business requires exact synchronicity between product offer and demand in consumer countries. Having tools that help to improve this synchronicity through predictions or crop growth monitoring could provide an important advantage to program standards and corrective agronomic practices. At the Centro de Biotecnología Agropecuaria, SENA (SENA's Biotechnology, Agricultural and Livestock Center), located in Mosquera, Cundinamarca, a trial with standard carnation cv. Delphi grown under greenhouse conditions was carried out. The objective of this study was to build a simple model of dry matter (DM) production and partition of on-carnation flower stems. The model was based on the photosynthetically active radiation (*PAR*) MJ m^{-2} d^{-1} and temperature as exogenous variables and assumed no water or nutrient limitations or damage caused by pests, disease or weeds. In this model, the daily DM increase depended on the *PAR*, the light fraction intercepted by the foliage (F_{LINT}) and the light use efficiency (LUE) g MJ^{-1}. The LUE in the vegetative and reproductive stages reached values of 1.31 and 0.74 g MJ^{-1}, respectively. The estimated extinction coefficient (k) value corresponded to 0.53 and the maximum F_{LINT} was between 0.79 and 0.82. Partitioning between the plant vegetative and reproductive stages was modeled based on the hypothesis that the partition is regulated by the source sink relationship. The estimated partition coefficient for the vegetative stage of the leaves was 0.63 and 0.37 for the stems. During the reproductive stage, the partitioning coefficients of leaves, stems and flower buds were 0.05, 0.74, and 0.21, respectively.

Key words: *Dianthus caryophyllus*, prediction, dry matter, partition coefficient, stems.

RESUMEN

El negocio de las flores de corte requiere una estricta sincronía entre la oferta del producto y la demanda en los sitios de consumo. Contar con herramientas que ayuden a mejorar esta sincronía mediante predicciones o monitoreo del cultivo puede significar una ventaja importante a la hora programar prácticas de manejo rutinarias o correctivas. En el Centro de Biotecnología Agropecuaria del SENA, ubicado en Mosquera, Cundinamarca, se estableció un ensayo en clavel estándar cv. Delphi en condiciones de invernadero. El objetivo del estudio fue construir un modelo simple de producción y distribución de masa seca en tallos florales de clavel. El modelo se basó en la radiación fotosintéticamente activa (*PAR*) MJ m^{-2} d^{-1} y la temperatura como variables exógenas y asume que no hay limitantes de agua, nutrientes o daño por plagas, enfermedades o malezas. En este modelo el incremento diario de masa seca dependió de la *PAR*, la fracción de luz interceptada por el follaje (F_{LINT}) y la eficiencia en el uso de la luz (LUE) g MJ^{-1}. El LUE para la etapa vegetativa y reproductiva alcanzó valores de 1.31 y 0.74 g MJ^{-1}, respectivamente. El valor estimado de k correspondió a 0,53 y la máxima F_{LINT} estuvo entre 0,79 y 0,82. La distribución entre las etapas vegetativa y reproductiva de la planta se modeló basada en la hipótesis de que la partición está regulada por la relación fuente vertedero. El coeficiente de distribución estimado para la etapa vegetativa para las hojas fue 0,63 y para el tallo 0,37. Los coeficientes de distribución en la etapa reproductiva fueron para hojas 0,05; tallos 0,74 y botón floral 0,21.

Palabras clave: *Dianthus caryophyllus*, predicción, materia seca, coeficiente de partición, tallos.

Introduction

Colombia is the main provider of cut flowers in the United States and the second exporter in the world with 205,407 t of fresh flowers, which have all been produced in an area of 7,200 ha, employing about 220,000 persons, directly and indirectly (Asocolflores, 2009). The standard carnation and mini carnation are the most important flower crops in the country, after roses, accounting for 18% of the cultivated area and with an export of 37,855 t (Asocolflores, 2009).

The demand for flowers in North America, Europe and Asia is closely linked to special celebrations; a market characteristic that forces a special coordination between the national supply and international demand. In order to maintain this synchronicity, it is necessary to have a deep knowledge of the growth and development dynamics of the

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species of interest as well as on the use of different tools that are intended for monitoring the production related physiological processes and for collaborating with making agronomic and administrative decisions.

Crop modelling gives quantitative information for the decision making of, for example, sowing season, irrigation, fertilizing, and pest and disease management, among others. In addition, it serves as a tool for estimating yield potential, water needs, fertilizer losses and other factors (Penning de Vries *et al.,* 1989; Gary *et al.,* 1998; Meira and Guevara, 2000).

Models are tools used to summarize knowledge, test hypothesis, describe and understand complex systems, and compare different situations; they are used as support for making decisions concerning production management and planning (Lentz, 1998; Marcelis and Gijzen, 1998).

Modelling simplifies, as much as possible, a situation that is being studied (Monteith, 1969) by representing, generally in a mathematical way, the system of interest (Goudriaan and Van Laar, 1994). The objective of modelling is to create a model that can work and imitate, as closely as possible, the real world or a real situation by means of a process known as simulation (Salazar, 2006).

A crop model predicts the final biomass production or the harvestable yield and facilitates the processes involved in plant growth and development (Jame and Cutforth, 1996), including phenology (Jones and Ritchie, 1990).

Accumulation of dry matter (DM) or crop growth can be modeled as a function of the photosynthetically active radiation (*PAR*), light use efficiency (LUE) and the extinction coefficient of light (*k*) (Tsubo *et al.,* 2005).

The objective of this study was to generate a model that simulates the potential yield and the total dry matter accumulation as well as per organ (stem, leaves and buds) of the floral stems of the carnation cv. Delphi.

Materials and methods

The investigation was carried out in the greenhouses of the Centro de Biotecnologia Agropecuaria of SENA in the municipality of Mosquera (Colombia). The geographical coordinates are 74.2° W, 4.7° N, with an altitude of 2,556 m a.s.l., mean annual precipitation of 645 mm, mean annual temperature of 14.7°C and 80% relative humidity. The data used in this research was gathered between June 28th and November 15th, 2008.

Rooted cuttings of standard carnation (*Dianthus caryophyllus* L.) variety Delphi (white color flowers) were used, which were donated by Suata Plants in Bogota. Sowing took place on May 15th on elevated beds measuring 15.00 x 0.85 m. Each bed consisted of two plastic containers. In this way, each bed was sown with 540 plants giving a sowing density of 24.7 plants/m^2 per greenhouse. *Pinching* was done on June 25th upon the 6th node, when the central lateral stems showed approximately four nodes.

These results come from a trial where the effect in growth and production of carnation were evaluated using three differences substrates: 1) 100% burned rice husk (100BRH); 2) mixture of 65% burned rice husk - 35% coconut fiber (65BRH); and 3) mixture of 35% burned rice husk - 65% coconut fiber (35BRH). Since no statistical differences between the substrates were found, the information from all the treatments was compiled into a unique data base with nine replications. The experimental unit was 12.8 m^2.

Fertigation was applied using an automatized irrigation equipment with four drip lines of 17 mm of diameter on each bed and type Hydro PCAD drippers incorporated every 20 cm and a flow rate of 1.2 L h^{-1}.

The climate variables were obtained from the agroclimatological station HOBO (Onset Computer Corporation, Bourne MA) located at the experimental site (in the greenhouse). The photosynthetically active radiation (*PAR*) was used for building the DM production and partition model. The *PAR* data were registered every 30 min obtaining 48 readings per day, of which 24 (light hours) were used to calculate the average and obtain the daily *PAR* value.

The sampling method applied to the research was of a destructive nature and each experimental unit was subdivided into 15 squares. Therefore, in each sampling, one square was randomly selected and two plants under perfect competition where plucked (central line and central row). Samplings were carried out every 15 d. From the sampled plants the variables total DM and DM per organ was determined (stem, leaves, bud). The obtained data were used to generate the DM production and partition model. A total of 11 destructive samplings were performed during the whole growing cycle until the first harvest peak.

These variables were determined after separating the different organs (leaves, stem and bud) from the flower stems:

Leaf area: obtained through direct measurement from the planimeter. A LICOR LI - 3100 leaf area meter (Licor, Lincoln, NE) was used. The obtained readings were expressed as cm^2 of leaf blade.

Dry matter: the different organs of the flower stem were dried in oven at 80°C until reaching constant weight (96 h). Once dry, the stems, leaves and flowers were weighed using a precision scale, determining the DM by organ and the total DM for each of the sampled plants according to the treatment.

Model description

For the development of the DM production and partition model data for the leaf area index (LAI) and photosynthetically active radiation (*PAR*) in MJ m^{-2} d^{-1} was used. The average daily data (12 h) were used for the *PAR*.

Daily growth rate

According to Tsubo *et al.* (2005), the daily increase in DM on a potential growth model can be directly calculated out of the received *PAR*, the fraction of intercepted light by the foliage (F_{LINT}) and the light use efficiency (LUE) (Eq. 1).

$$\delta W_t = LUE\ F_{\mathrm{LINT}} PAR_t \tag{1}$$

Where, δWt is the daily growth increase expressed as g m^{-2} d^{-1}, LUE is the light use efficiency in g MJ^{-1}, F_{LINT} is the fraction of light intercepted by the crop and *PAR* is the photosynthetically active radiation expressed as MJ m^{-2} d^{-1} (Monteith, 1969; Gosse *et al.,* 1986; Kooman and Jones, 1995; Salazar *et al*., 2007). Equation 1 includes two estimated parameters, LUE and F_{LINT}, since the *PAR* was a direct measuring variable obtained from the HOBO station.

LUE is an important parameter in crop development because it represents the balance between photosynthesis and respiration. Factors affecting these processes also affect LUE and, hence, crop growth and development. LUE changes according to crop development (Kooman and Spitters, 1995).

Equation 2 was used for calculating F_{LINT}, since light interception by the foliage can be described as a function of the leaf area index (LAI) increase (Kooman and Spitters, 1995; Salazar *et al*., 2007).

$$F_{\mathrm{LINT}} = 1 - e^{-kLAI} \tag{2}$$

Where *k* is the extinction coefficient of the light and LAI is the leaf area index.

Estimation of the parameters *k* and LUE was performed using a non-lineal iterative procedure that minimized the sum of squares between the observed values and the simulated values using the Solver tool of Microsoft Excel®. Using the NLIN procedure of the SAS statistical package, the variable LAI was modeled from the leaf area (LA) data, which were obtained directly from the destructive sampling. The adjusted model was logistic, $Y=\alpha/1+e^{-\beta(t-\gamma)}$, where α is the maximum leaf area value, β is the parameter determining the slope of the growth curve, and γ is the moment at which maximum growth rate was achieved (SAS Institute, 2003).

Dry matter simulation

Once the daily DM growth rate model was developed (Eq. 1), the simulation of total daily DM was carried out (Eq. 3) using the Euler method:

$$W_t = W_{t-1} + \delta W_t \Delta t \tag{3}$$

Where, W_t is the total DM at time t (g m^{-2}), W_{t-1} is the total DM at time t-1 (g m^{-2}), δW_t is the daily DM growth rate at time t (g m^{-2} d^{-1}), and Δt is the increase over time (1 d) (Van Kraalingen, 1991; Salazar *et al*., 2007).

Dry matter partitioning

The total DM was distributed among the different organs of the flower stem according to the vegetative (before onset of flower bud) and reproductive (from onset of flower bud until harvest) stages. The biomass partitioning was calculated on the supposition of competition for assimilates between the different plant organs in a way in which each organ receives a proportion of the total DM. Partitioning varies according to the developmental stage of the crop (Marcelis, 1994).

The partitioning coefficients α_o were the proportions of the total dry matter that were assigned to the stems, leaves and buds. Estimation of the α_o values was performed using a non-lineal iterative procedure that minimized the sum of squares between the observed values and the simulated values using the Solver.

The simulation of DM partitioning on the different plant organs was carried out applying the Euler method through Eq. 4.

$$W_{ot} = W_{o(t-1)} + \alpha_o \delta W_t \Delta t \tag{4}$$

Where, W_{ot} is the total DM of an organ: stems (W_{st}), leaves (W_{sh}) or buds (W_{sb}), at day t (g m^{-2} d^{-1}); $W_{o(t-1)}$ is the DM of each organ as follows: stems (W_{st-1}), leaves (W_{sh-1}) or buds (W_{sb-1}) at day t-1 (g m^{-2} d^{-1}), α_o is the partitioning coefficient in stems (α_t), leaves (α_h) or buds (α_b); δW_t is the total daily DM growth rate (g m^{-2} d^{-1}) and Δt is the growth over time (1 d).

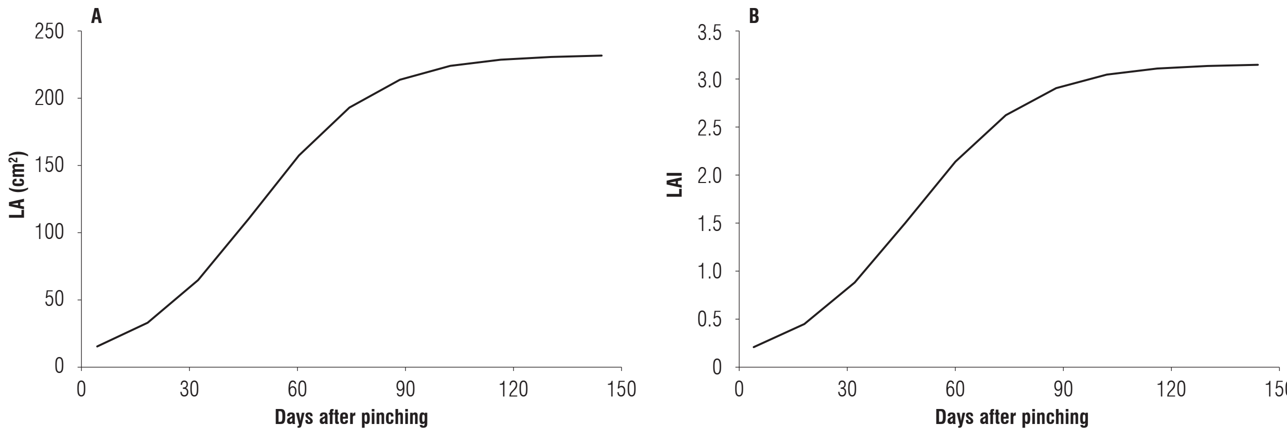

FIGURE 1. Behavior of leaf area (LA) and leaf area index (LAI) of flower stems of the standard carnation cv. Delphi as a function of the days after *pinching*.

Results

Leaf area

The leaf area (LA) of the carnation flower stems was adjusted to a logistic growth model using a general formula: $Y=\alpha/1+e^{-\beta(t-\gamma)}$. Tab. 1 and Fig. 1 show the estimated values of the parameters α, β and γ as well as the behavior of LA over time.

TABLE 1. Estimated values for the logistical model parameters regarding the variable leaf area of flower stems of the standard carnation cv. Delphi.

Parameter	Estimated	UL	LL
α	232.4	226.0	238.7
β	0.061	0.054	0.069
γ	47.6	45.3	50.0

α = maximum value of leaf area; β = curve slope; γ = DAP, when maximum AGR (absolute growth rate) is achieved. UL, upper limit (95% confidence interval); LL, lower limit.

The maximum LA of the flower stems was 232.4 cm^2, with a critical period for growth at around 48 DAP, where the highest absolute growth rate (AGR) of leaf expansion was reached.

On the other hand, the leaf area index (LAI) and (LA) presented similar behaviors with maximum LAI values of 3.14, which were reached around 90 DAP. This LAI level was maintained until the flowers stems were cut.

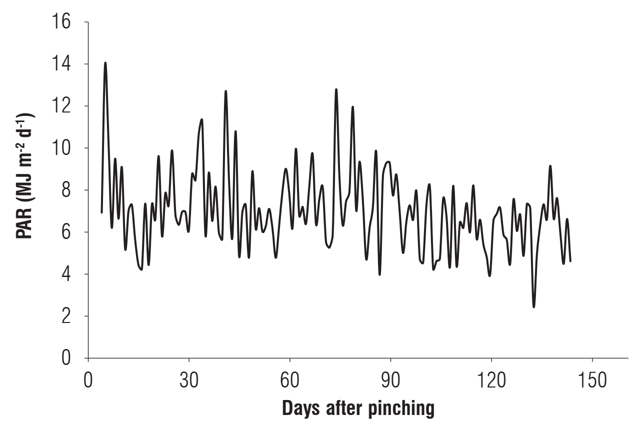

FIGURE 2. Behavior of the photosynthetically active radiation (*PAR*) during the months of June and November 2008 at the Centro de Biotecnología Agropecuaria of SENA in Mosquera, Cundinamarca.

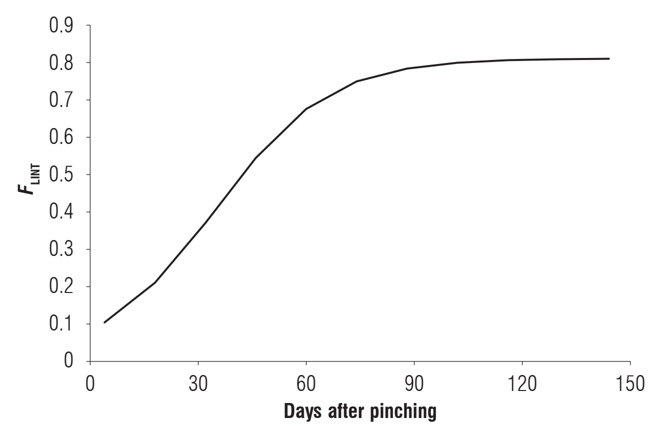

FIGURE 3. Behavior of the fraction of intercepted light (F_{LINT}) by flower stems of the standard carnation cv. Delphi.

Photosynthetically active radiation and fraction of intercepted light

The photosynthetically active radiation (PAR) received in the greenhouse showed a fluctuation between 2.46 and 13.99 MJ m^{-2} d^{-1} (Fig. 2).

During the production cycle, the crop received 989.18 MJ m^{-2} *PAR* with a daily average of 7.01 MJ m^{-2} d^{-1}. In turn, the fraction of intercepted light F_{LINT} (Fig. 3), calculated according to Eq.2, showed a similar behavior as that of the LAI (Fig. 2), with maximum values of 0.80, which were reached around 80 DAP.

Extinction coefficient (k) and light use efficiency (LUE)

In this study, k was determined through the iterative minimization method using the Solver, which reported a value of 0.53 (Tab. 2).

TABLE 2. Values of the extinction coefficient of the light (k) and light use efficiency (LUE) for the carnation crop.

Developmental stage	Parameter	
	k	LUE (g MJ^{-1})
Vegetative	0.53	1.31
Reproductive	0.53	0.71

Under this research, the growing cycle was divided into two stages and a LUE value was calculated for each of them. However, the two stages do not correspond to the vegetative and reproductive phases but to the initial and lineal growth phases on the curve (LUE1) and to the maintenance phase (LUE2). This division was done in order to determine the DM production in a more fitted way through the simulation model. Therefore, the values of LUE1 and LUE2 determined in this research correspond to 1.31 and 0.71 g MJ^{-1}, respectively (Tab. 2).

Dry matter growth, production and partitioning

The total DM growth rate was calculated from Eq. 1. The average rate during this trial was 4.96 g m^{-2} d^{-1}, showing maximum and minimum values of 12.70 and 0.68 g m^{-2} d^{-1}. During the vegetative stage (71 d), the rate reached average values of 4.31 g m^{-2} d^{-1}; whereas, during the reproductive stage (70 d), it reached 5.63 g m^{-2} d^{-1}. Both absolute maximum and minimum levels in the growth rate were achieved during the vegetative stage of the crop. In turn, the values of the minimum and maximum growth rate during the reproductive stage corresponded to 1.40 and 12.10 g m^{-2} d^{-1}, respectively.

Total DM partitioning was carried out for both the vegetative and reproductive stages. During the vegetative stage, the DM of the leaves and stem was considered; while during the reproductive stage leaves, the stem and flower bud were considered.

Figure 4 shows the observed and simulated total DM values of the carnation flower stems as well as their different constituent organs (stems, leaves and flower buds). Regarding DM accumulation in the leaves, a constant biomass can be observed after 80 DAP.

Table 3 shows the estimated values for the main parameters of the DM production and partitioning model. During the vegetative stage (71 d), 37% of the DM produced by the plant was assigned to stem growth, while the remaining 63% was directed to leaf growth.

TABLE 3. Estimated values of dry matter partitioning coefficients in the standard carnation cv. Delphi.

Developmental stage	Parameter		
	α_t	α_h	α_b
Vegetative	0.37	0.63	---
Reproductive	0.74	0.05	0.21

α_t: partitioning coefficient for the stem; α_h: partitioning coefficient for leaves; α_b: partitioning coefficient for the flower bud.

Seventy days after pinching, the flower bud appeared as a new sink organ on the stem, a phenomenon that modifies the DM partitioning on the inside of the plant and, thus, the partition coefficients varied. Therefore, during the vegetative stage, 74% of the produced DM was assigned to the stem, with 5% to the leaves and the remaining 21% was directed to the flower bud (Tab. 3).

Finally, Fig. 4E shows the integrated models (DM of stems, leaves, flower buds and total DM). The observed and simulated values are presented in an integrated manner for the different organs of the carnation flower stem. The simulated values show the same trend as the observed values. In the same way, Fig. 4 shows the root square mean error for each case (RSME), a statistical parameter with values considered low since their size was generally below 10% of the variable's maximum value.

Discussion

Leaf area

The maximum LA value in the stems that was determined in this research is comparable with the values obtained by Cárdenas *et al.* (2006), who reported maximum leaf areas in whole plants of the carnation cv. Nelson (five flower stems) ranging from 995.9 to 1172.0 cm^2, which means between 199.2 and 234.4 cm^2 per flower stem.

From the LAI values, it is possible to state that, in a carnation crop for each m^2 of sown soil or area, there are 3.14 m^2 of leaves responsible of taking part in the photosynthetic process. The observed LAI values are lower than the value of 6.0 determined by Partridge *et al.* (1983) for carnations grown in California and the LAI values between 4.0 and 5.0 reported by Cárdenas *et al.* (2006) in the carnation cv. Nelson grown with the same types of substrate.

Likewise, these LAI values are lower than the ones reported by Lee *et al.* (2002) for other ornamental species, such as the chrysanthemum, who determined LAI values from 4-8 using plant densities of 32-64 plants/m^2. Dennett and Ishag (1998), working with the pea (*Pisum sativum*)

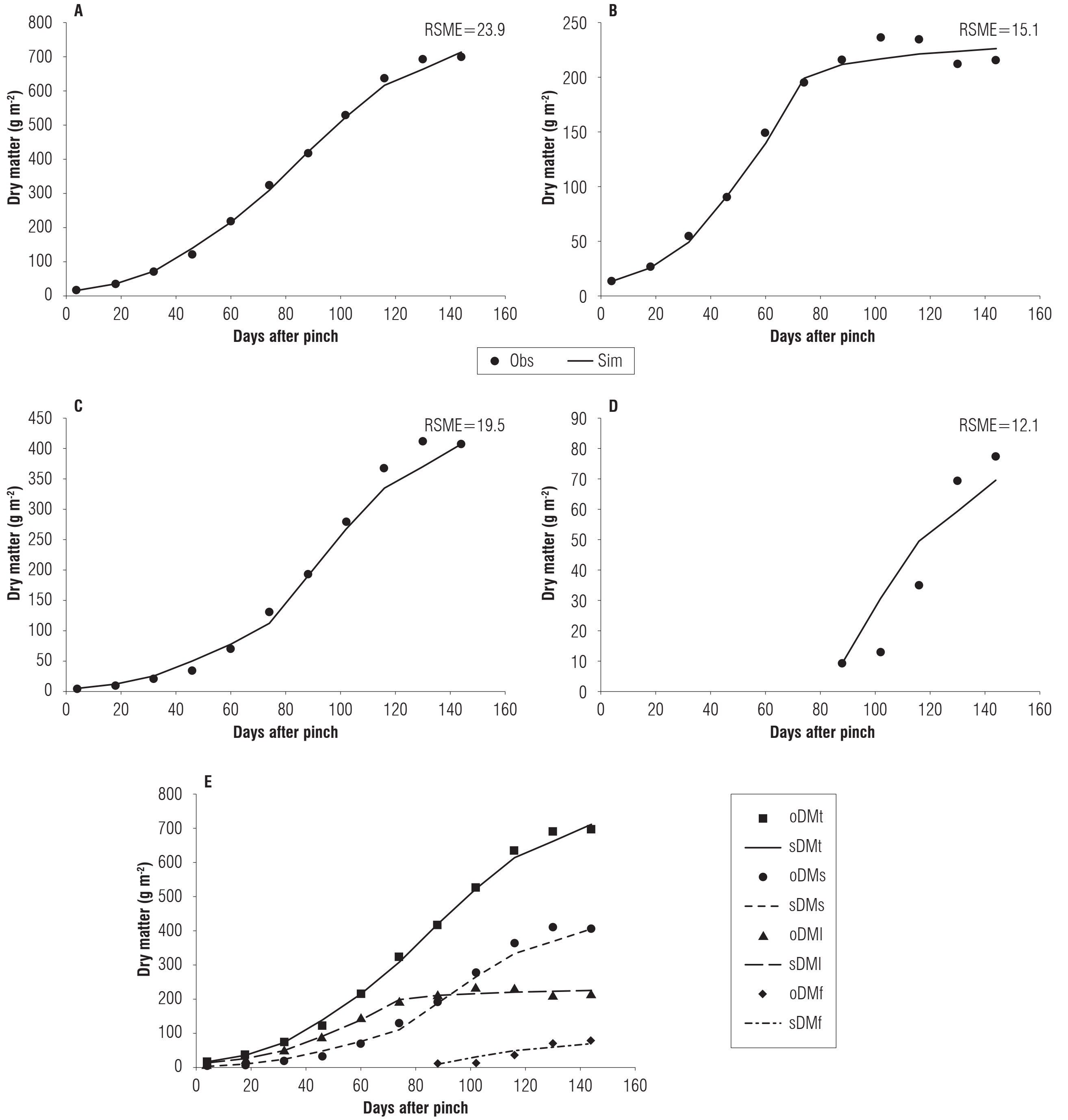

FIGURE 4. Observed and simulated values of total dry matter of complete flower stems. A, stem dry matter; B, dry matter of leaves; C, dry matter of flower buds; D, whole dynamic; E, as a function of days after *pinching* (DAP). Obs, observed values; Sim, simulated values; t, total; s, stems; l, leaves; f, flower buds.

and broad bean (*Vicia faba*), reported maximum indexes of 6.3 and 4.2, respectively, using plant densities of 80 plants/m^2 in the pea and 20 plants/m^2 in the broad bean. In horticultural species such as broccoli and cabbage, Carranza *et al.* (2008) showed maximum LAI values of 1.76 and 5.17, respectively.

Photosynthetically active radiation and fraction of intercepted light

The mean value for the PAR of 7.01 MJ m^{-2} d^{-1} determined in this research is similar to the 7.24 MJ m^{-2} d^{-1} found by Salazar (2006) in Chía, Cundinamarca, also under greenhouse conditions.

The fraction of intercepted light "F_{LINT}" presented a similar behavior to LAI (Fig. 2), a response that can be attributed to the fact that the extinction coefficient of light (k) together with the LAI are the only variables that F_{LINT} depends on. At the end of the growing cycle, the flower stems of the carnation captured 80% of the incident *PAR*. The maximum F_{LINT} values in the carnation were higher than those found in species such as quinoa, where only values from 0.33 to 0.51 were achieved, with LAI values from 0.61 to 1.38 (Ruiz and Bertero, 2008).

Extinction coefficient and light use efficiency

The extinction coefficient k determines the rate at which solar radiation is absorbed by unit of leaf area and depends on the inclination angle of the incident rays and the position and orientation of the leaves. The extinction coefficient of the light of 0.53 determined for the carnation indicates that, for each LAI unit that is penetrated by *PAR* radiation in the canopy of carnation, 40.9% ($1-e^{-k}$) of the light will be absorbed.

The LUE values of 1.31 and 0.71 g MJ^{-1} indicate that, during the initial and lineal growth phases, the carnation flower stems produced 1.31 g of DM for each MJ of light intercepted by their leaves. In the maintenance phase of the growth curve, these same stems produced 0.71 g of DM for each MJ of intercepted light. This response indicates that the DM production efficiency in the carnation stems was higher during the first growth phases, which explains the fast development of the leaves and stems, which were the only organs present at this stage. In the final stage of the cycle, the DM production efficiency decreased, consistent with the growth reduction of the leaves and stems, but in contrast to the accelerated growth of the flower bud.

It is worth noticing, that the LUE value determined here is lower than in other cut flowers. This event is due to the fact that flower stems of carnation do not show an elevated DM accumulation during their whole cycle. Therefore, the maximum DM values of 5.0 to 5.3 g were obtained after 144 d, while, in other species of flowers such as chrysanthemum, Lee *et al.* (2003) reported DM accumulation of 500-600 g in approximately 80 days, with estimated LUE values at different light and plant density levels ranging from 3.47 and 6.91 g MJ^{-1}. The maximum DM values in the stems found in this study are lower than the values of 10 g per stem that were published by Partridge *et al.* (1983) in the carnation variety Davies in the United States of America.

The LUE value depends on the crop, management, sowing density and temperature. In this way, Haxeltine and Prentice (1996) stated that, as temperature increases, LUE decreases; a fact that is explained by the balance change between photosynthesis and respiration (decrease in photosynthesis and increase in respiration). The LUE values estimated in this research are lower than those for other species of cut flowers, such as the chrysanthemum, reporting values of 3.4 (summer) and 5.3 (winter) g MJ^{-1} (Lee *et al.,* 2002).

In the cape gooseberry, Salazar *et al.* (2007) determined LUE values of 0.46 and 2.62 g MJ^{-1} for the vegetative and reproductive stage, which are much higher values than those found in the carnation cv. Delphi. These results, as well as those with chrysanthemum, broccoli and cabbage, are consistent with the elevated DM accumulation rates of 8,000-9,000 g in 400 d.

The LUE levels in g MJ^{-1} reported for other species are diverse. For example, in the potato, it is possible to find values between 2.1 and 3.2 (Kooman and Spitters, 1995), and at 1.6 and 1.25 in maize and sorghum, respectively (Muchow and Davies, 1988); 3.5 and 4.0 in barley and pea, respectively (Berntsen *et al.,* 2004), 1.81±0.05 in wheat (O'Connell *et al.,* 2004); between 1.98 and 5.03 for cauliflower (Kage and Stützel, 1999), 1.80 for sugar cane (Keating *et al.* 1999), and between 1.25±0.09 and 2.68±0.15 for quinoa (Ruiz and Bertero, 2008).

According to the obtained results, it is possible to infer that either days with higher *PAR* levels or light management techniques could help increase biomass production in flower stems and, hence, favor the improvement of variables of agronomic interest, such as length, width, weight and postharvest life of stems.

Dry matter growth, production and partition rate

The total DM production and accumulation, as well as partitioning to the different constituent organs of the flower stem (stem, leaves and flower bud), presented a distinct equivalence between the simulated and observed values, which is a characteristic that, together with the low total and per organ values of the root square mean error (RSME), indicates a satisfactory adjustment of the model in all of the cases.

The pattern of DM partitioning during the vegetative stage of the carnation crop indicates that, during the initial growth stages, matter increase is a priority and, hence, leaf area. This behavior can be attributed to the necessity of the crop to favor its growth by capturing the highest amount of *PAR* in the shortest time possible. Achieving the aforementioned guarantees that the crop can rapidly reach the critical LAI or the LAI value by which 95% of the incident radiation is captured.

For the reproductive stage the largest proportion of DM was assigned to the stems, a behavior indicating active growth that is mainly directed to increasing the length and diameter of this organ. Apart from that, the leaves drastically reduced the amount of DM received (63 to 5%), which indicates a reduced growth during this stage due to the accelerated DM accumulation that took place during the vegetative stage.

On the carnation stems, the onset of nodes and, therefore, leaves stops when the flower bud appears, *i.e.* after 18-19 nodes or 1363.2 degree day (López *et al*., 2010). Finally, the flower bud is, after the stem, the biggest DM sink at this stage, which is an unexpected characteristic considering that the flower is the reproductive organ of the plant and that its growth happens in a shorter period of time in relation to the stem and leaves.

The severe reduction in the proportion of DM distributed to the leaves has also been documented by authors such as Salazar *et al.* (2007) in the cape gooseberry, who showed a reduction from 72 to 9% of the distributed DM due to the shift from the vegetative to reproductive stage. A similar situation was also reported in broccoli with a reduction from 46.6 to 14.2% due to the same phenomenon (Carranza *et al.,* 2008).

The comparison between the simulated and observed values as well as the low RSME values indicates a satisfactory adjustment of the simulation model for any of the studied organs. According to these results, the model developed in this research project could be a potentially useful tool for predicting DM production and partitioning in the carnation cv. Delphi.

Conclusions

The efficiency in DM production during the first development stages of the flower stem was higher than in the final stages, which was verified by the higher LUE values during the first months of the growing cycle. In this way, during the first developmental stages, water management, nutrients and *PAR* radiation are factors that are especially critical in relation to the accumulation of high DM contents in flower stems.

In general, the simulated data in each of the models followed the same trend as the observed data, as supported by the low RSME values. In this way it can be concluded that the fit of all the models was satisfactory and, therefore, they can be used to predict DM production and partitioning in the standard carnation cv. Delphi under the prevailing conditions of the savanna of Bogota in the absence of limitations such as water, nutrients and biomass reduction caused by pests and diseases.

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