

3D Modelling of growth and ornamental quality of chrysanthemum at different plant densities

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Introduction

Adaptation of plant form, growth and ornamental quality to local climatic conditions has been reported frequently. In commercial practice, such conditions are continuously manipulated, by e.g. change of plant density, level of assimilation light and temperature regime. The question how the plants react on these changes is of scientific and, ultimately, economic importance. Model simulation of the effects of different cultivation strategies may help growers in their decision making. Local climate conditions can best be described by 3D models that quantify interactions between local microclimate and local plant organs.

For chrysanthemum, both FSPM (Functional Structural Plant Model), dealing with growth and shape at the organ scale (De Visser et al., 2006), and mechanistic models, operating at the crop level (Lee and Heuvelink, 2003; Larsen and Gertsson, 1992), have been developed. To what extent do FSPM render better results in explaining effects of horticultural measures? Crop level models necessarily require some assumptions with regards to effects of light on morphogenesis, which could be tackled by 3D models explicitly. For example, leaf thickness (Acock et al., 1979) and indentation (Spaargaren, 1996) will be affected by the local light level during its growth. A 3D plant model should incorporate carbohydrate dynamics and temperature driven organ developmental processes to account for such effects, i.e. a coupling of function and structure. Our FSPM of chrysanthemum (De Visser et al., 2006) is able to simulate such processes.

In this paper the outcomes of the 3D model are compared to the greenhouse observations and to conventional, 1-D calculations of light interception. Since chrysanthemum plantings are more or less homogeneous in the horizontal, effects of simplifications of the 3D light model to a typical Lambert-Beer approach on the simulation results were tested. The use of properties in the 3D model that were determined at the crop level and not at the organ scale, like observed specific leaf area (SLA) and scattering coefficients, are evaluated. For this, crop properties and plant growth at two different planting densities and two temperature regimes were used. The tests can indicate at which scale specific properties are required to give acceptable model results. The reported model functionality will be most useful to understand and predict response of chrysanthemum plants to a number of cultivation measures commonly used in commercial practice.

Model description

The FSPM of Chrysanthemum consists of three modules:

1. An architectural module, describing the spatial properties and development of the plant-organs in terms of symbols, according to the L-alphabet (e.g. Lindenmayer and Prusinkiewicz, 1990).
2. A light-interception module, which takes as input the 3D-scene, including the position and intensity of photosynthetic active radiation (PAR) of the light sources. The nested radiosity model, developed by Chelle and Andrieu (1998), is used to calculate the absorbed PAR at every leaf.

3. A carbon module, which consists of two sub-modules:

- an assimilation module according to the biochemical model of Farquhar (Farquhar et al., 1980), which calculates the hourly produced amount of assimilates per leaf.
- a sink/source module, which takes into account the maintenance respiration and the assimilate distribution over the various plant organs according to a relative sink strength model (Marcelis, 1996). The hourly assimilation per leaf is aggregated to plant level each day and distributed over the plant.

For further model details we refer to De Visser et al. (2006).

Experiment

A greenhouse experiment was carried out with cuttings of chrysanthemum, cultivar Reagan Improved, that were planted at two densities (32 and 64 plants per m²), each density grown at temperature set points of 16 and 20°C respectively. All four treatments were duplicated. Growth started 4th November 2004 and ended between 24th January and 14th February depending on the treatment. Assimilation light was provided for 18 and 8 hours in long day (LD) and short day (SD) period respectively at 44 μmol PAR m⁻² s⁻¹. Light extinction at diffuse light conditions was measured (n=6) 10 times during crop development.

The model, calibrated for a growth chamber trial (see De Visser et al., 2006), was validated on the greenhouse data set. At three moments during crop development, when the plants carried 8, 14 and 33 leaves respectively, plant structure in the L-system was fixed and light extinction simulation by the radiosity model was calibrated by adjusting its reflection and transmission coefficients. For this, diffuse light was assumed to originate from 12 light sources, distributed along the hemisphere following Goudriaan and Van Laar (1994). Direct light followed the solar track, and assimilation light originated from the azimuth only.

Results

Light extinction of PAR strongly increased during growth to values above 95% of incoming light at harvest, as illustrated for the high plant density in Fig. 1. A Lambert-Beer relationship with a 0.8 extinction coefficient could be fitted from the data of this density. Similarly, the radiosity model

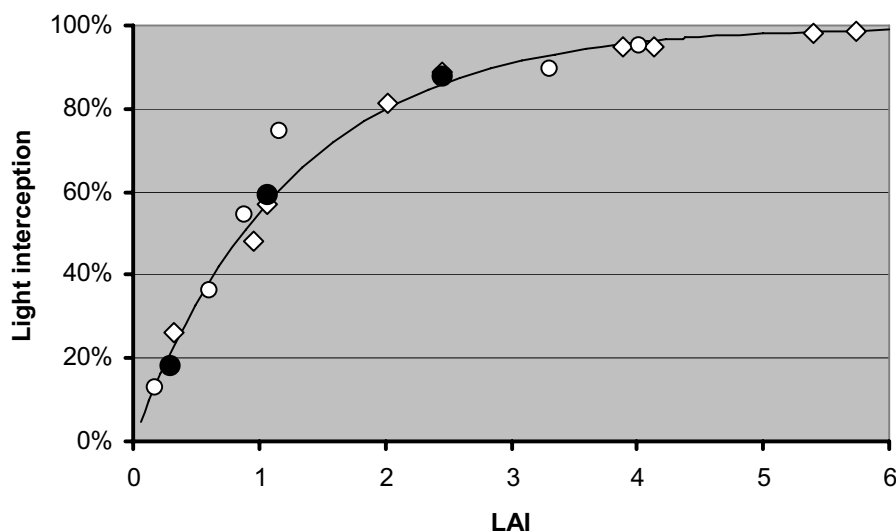


Fig. 1. Light interception in relation to LAI in the low (open circles) and high (diamonds) plant density treatment. Filled circles, radiosity model; Line, fitted Lambert-Beer relationship

simulated light extinction correctly with calibrated reflection of 15% and transmission of 20% (Fig.1). This relationship was valid for both plant density treatments, although at LAI of ca. 1 in the low plant density treatment a slightly higher extinction was observed, which might be attributed to formation of side shoots. On basis of the values for photosynthesis, allometry and respiratory losses, as determined in an earlier study (De Visser et al., 2006), for most of the greenhouse treatments simulated plant growth was comparable to the observations (Table 1).

Table 1. Total simulated plant biomass (g DM) for 4 treatments at harvest. Observed : between brackets.

	16°C	20°C
32 pl m ⁻²	11.2 (10.0)	7.6 (8.1)
64 pl m ⁻²	8.8 (6.2)	5.1 (5.0)

In the 20°C treatment SLA was ca. 7% higher at the highest plant density, and combined with the higher number of plants resulted in an LAI of 5.4. At the low plant density LAI was 4.0, caused by heavy leaves and enhanced side shoot formation. The 3D plant model simulated a higher number of side shoots at the lower density, because the model relates this number to the plant biomass during the time frame of bud break (see De Visser et al., 2006). The increase of side shoots and, thus, area for light interception, caused an increase in biomass relative to the higher density plants. The slight change of SLA at the high density was not incorporated in the model: leaf area was directly proportional to leaf weight. Ornamental quality was increased at the lower plant density due to an increase in flower number and, less pronounced, an increase in flower weight. A more detailed comparison of simulation results and greenhouse data will be presented extensively in a full paper.

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