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Modelling the effects of soil water potential on growth and quality of cut chrysanthemum (*Chrysanthemum morifolium*)

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ABSTRACT

A complete dynamic model was developed to describe the effects of soil water potential (*WP*) on the growth and external quality of standard cut chrysanthemum (*Chrysanthemum morifolium*) in order to optimise water management of greenhouse crops. Experiments using chrysanthemum cv. 'Jinba' with different planting dates and levels of water treatment were conducted in a lean-to type greenhouse from 2006 to 2008. The dynamics of leaf area index (LAI), dry matter partitioning, and external quality traits (plant height, number of leaves per plant, flower-head diameter and peduncle length) were first determined as functions of accumulated photothermal index (*PTI*). Impacts of *WP* on leaf photosynthetic rate, LAI, dry matter partitioning, and the external quality traits were quantified via introducing the experimentally identified effects of *WP* on the parameters in the light response curve of leaf photosynthetic rate and the *PTI*-based functions. These quantitative relationships were incorporated into a generic crop growth model SUCROS. Using independent experimental data, the model was found to give good predictions for biomass production, dry weight of organs, and the external quality traits of the chrysanthemum cultivar grown under different levels of water supply. The coefficient of determination (r^2) between the predicted and measured results was 0.91 for LAI, 0.88 for biomass production, and varied between 0.83 and 0.93 for organ dry weight and the external quality traits. Further evaluation is needed when applying this model to a wider range.

1. Introduction

Chrysanthemum (*Chrysanthemum morifolium*), the second cut flower after rose, dominates the global cut flower market (Spaargaren, 2002). In Japan, cut chrysanthemum represents 35% of the total cut-flower production (Boase et al., 1997), having China as one of the main suppliers (Ma, 2007). Over 90% of the cut chrysanthemum exported from China to Japan is the standard type, namely single stem and flower (Chen, 2005).

In China, the traditional lean-to type greenhouse is one of the major types of greenhouses used for year-round cut chrysanthemum production due to its energy saving and low investment (Luo, 2006). In lean-to type greenhouses, the standard cut chrysanthemum crop is usually soil cultivated and irrigated by means of flood irrigation. Frequent irrigation and poor ventilation due to the special structure of the greenhouses result in high humidity. Besides the low water use efficiency, this leads to disease problems and poor product quality for the crops. Therefore, the optimisation of water management for crops grown in greenhouses is of utmost importance to guarantee product quality, which usually plays a crucial role in the selling price of ornamental crops (Carvalho and Heuvelink, 2004).

Photosynthesis, biomass production and dry matter partitioning are essential for guaranteeing the external quality of ornamental plants. Water potential is one of the most important factors affecting these processes (Jones and Tardieu, 1998; Osório et al., 1998; Peri et al., 2003). Therefore, quantifying the effects of water on crop growth processes and external quality is an essential step to optimise water management for ornamental crop production.

There are many modelling studies on the effects of water on LAI (Chenu et al., 2008; Yang et al., 2009), leaf photosynthesis (Ferreyra et al., 2003; Wang et al., 2006), biomass production (Arora and Gajri, 1998, 2000; Eitzinger et al., 2003; Benli et al., 2007; Timsina et al., 2008) and dry matter partitioning (Folkard et al., 2005; Kumar et al., 2006) of field crops. Less attention has been paid to horticultural crops (Kage and Stützel, 1999; Han et al., 2003;

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Table 1
General information on four greenhouse experiments using cut chrysanthemum. Dates are expressed as day of the year (day 1 = 1 January).

Exp#	Year	Planting date	Treatment beginning	Duration of SD[a] (d)	Harvesting date[a]	Daily total PAR[b] (MJ m^{-2})	Temperature[b] (°C)
1	2006–2007	239	253	24, 24, 26, 30	352, 352, 6, 12	3.21 ± 1.52	19.14 ± 2.70
2	2007	11	30	23, 24, 26, 30	127, 134, 149, 164	3.91 ± 1.77	19.38 ± 3.03
3	2007–2008	273	289	21, 25	33, 44	2.74 ± 1.26	16.95 ± 2.10
4	2008	53	65	21, 23	164, 176	4.65 ± 2.08	19.51 ± 3.57

[a] Data are for different treatments from higher soil water potential to lower soil water potential. For example, '24, 24, 26, 30' stands for, respectively, duration of SD of −4 to −10 kPa, −10 to −20 kPa, −20 to −30 kPa and −30 to −50 kPa.
[b] Data are shown as average ± s.e. over the whole cultivation period.

Gutierrez Colomer et al., 2006). Several models have also been reported for predicting chrysanthemum crop growth and development (Heuvelink et al., 2002; Lee and Heuvelink, 2003; Ploeg and Heuvelink, 2006; Ploeg et al., 2007; Larsen and Nothnagl, 2008) and external (visual) quality (Carvalho and Heuvelink, 2001; Heuvelink et al., 2001; Dai et al., 2008). Those models were mostly focused on the effects of climate conditions (namely temperature and light) and plant density. However, studies on the effects of water potential on growth (Mortensen, 2000; Blom Zandstra and Metselaar, 2006) and external quality (de Farias et al., 2004; de Farias and Saad, 2005) of chrysanthemum are relatively limited and mainly qualitative. For the optimisation of water management, a complete model is needed for quantitatively accessing impacts of soil water potential on growth processes and external quality traits of the ornamental crop.

The objective of this study was to develop a complete dynamic model to predict the impacts of soil water potential on the growth and external quality of soil grown cut chrysanthemum, in order to facilitate the optimisation of water management for its production. For this purpose, four experiments with different planting dates and levels of soil water treatment were conducted in a lean-to type greenhouse to collect data for model development and validation.

2. Materials and methods

2.1. Plant material and growth conditions

A total of four experiments were carried out in a lean-to type greenhouse ($l \times w \times h = 50\,m \times 8\,m \times 3.2\,m$) located at Beijing (39°39′N, 116°37′E) from August 2006 to July 2008. The greenhouse was east–west oriented and had a north wall of 2.4 m high. Its front roof frame has the shape of a combination of circle (the lower 1/3 part) and parabola (the upper 2/3 part) curve, and the back roof has a slope of 39°. The north, east and west walls are composed of double layer brick texture, with a thickness of 0.16 m. The front roof frame is made of steel tubes and covered with anti-drop polyvinyl chloride (PVC) film. Along the north wall and the south edge, heating pipes were installed for heating the greenhouse during winter season. There is a thermal insulation screen (Shengri, Shengri Group, Beijing, China) that prevents the thermal radiation and sensible heat losses from the greenhouse from late afternoon to the next early morning during winter season.

Uniform rooted cuttings of standard cut chrysanthemum (cv 'Jinba'), with an initial plant height of 0.08 m and nine leaves per plant, were planted in 10 L plastic pots filled with soil and arranged at a density of 57 plants m^{-2}. Plants were grown under long day (LD) conditions (15 h) until the plant height reached 0.6 m, followed by short day (SD) period (10 h) up to harvesting. LD conditions were provided by 40 W fluorescent lamps (Xinghe, Tianye Group Co. Ltd., Shenzhen, China) during the night (22:00–02:00), and SD (07:00–17:00) period was enforced by using a blackout screen. Standard cultivation practices for fertilization, flower bud removal, disease and pest control as used for commercial standard cut chrysanthemum production in China were employed for growing the crops during the four experiments.

2.2. Water treatment design

The soil used in this study reached its field capacity when soil water potential was −4 kPa. According to de Farias et al. (2003, 2004), the external quality of chrysanthemum decreased significantly when soil water potential reduced to −30 kPa. To investigate the critical soil water potential, four levels of water treatments were used in Exp. 1 (−4 to −10 kPa, −10 to −20 kPa, −20 to −30 kPa, −30 to −50 kPa, indicated by the lower limit value, i.e. −10 kPa, −20 kPa, −30 kPa, −50 kPa respectively, hereafter) and Exp. 2 (−4 to −20 kPa, −20 to −30 kPa, −30 to −40 kPa, −40 to −50 kPa). According to the results of Exps. 1 and 2, −20 kPa was determined as the critical soil water potential for our cultivar; thus two levels of water treatments (−4 to −20 kPa, −25 to −40 kPa) were used in the subsequent experiments (Exps. 3 and 4).

In each water treatment of the four experiments, soil water potential at 0.1 m below the soil surface was monitored using tension meters with 3 replicas. Plot (composed of 12 pots) with 3 replicas for each water treatment was arranged with randomised block. To reduce the shading effects of the west and east walls, all plots were arranged within the centre part of the west–east orientation. Details on dates of planting, water treatment and harvesting, and duration of SD are listed in Table 1. In each treatment, when the soil water potential at 0.1 m below the soil surface had reached the target lower limit value, the plants were irrigated until the soil water potential reached the established upper limit value. In order to estimate the required amount of irrigated water for each

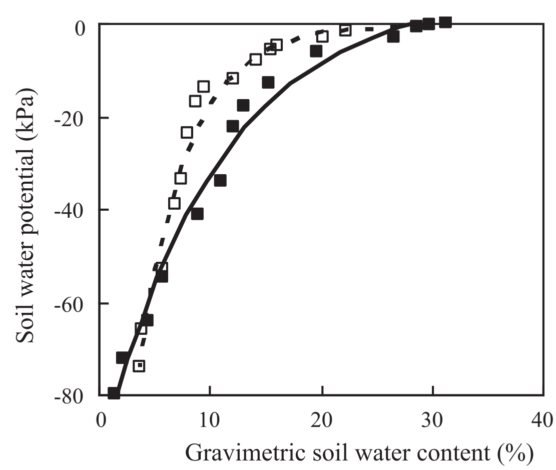

Fig. 1. Relationship between the soil water potential and the gravimetric soil water content (□ measured data of Exps. 1 and 2; ■ measured data of Exps. 3 and 4; -- fitted curve of Exps. 1 and 2; — fitted curve of Exps. 3 and 4). The fitted curves were based on Eq. (1), and the values of empirical coefficients derived from the fitting curve are: for Exps. 1 and 2, $a_1 = -0.48$ kPa, $a_2 = 172.45$ kPa, $a_3 = 4.33$; for Exps. 3 and 4, $a_1 = 7.00$ kPa, $a_2 = 102.51$ kPa, $a_3 = 10.62$.