Dynamic Climate Control in Combination with Average Temperature Control Saves Energy in Ornamentals

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Abstract

In the past decades, attempts have been made to produce pot plants in dynamic environments based on models for plant growth and gas exchange aiming at a reduced energy use. The energy minimising and daylight dependent control system IntelliGrow has been developed for production of pot plants and vegetables. Its basic principles are simple, as temperature and CO_2 concentration are regulated according to outdoor Photosynthetic Photon Flux Density (PPFD), based on photosynthesis models.

The experiments in spring 2003 included six climate strategies. Four were dynamic controls optimized to 80% or 90% of potential photosynthesis with a base temperature of 15 or 17 °C, in all cases with ventilation at 30 °C. Two reference climates were used; one of 18 °C day and 17 °C night temperature and one average temperature control set at 18 °C, both ventilated at 4 °C above the temperature set point. A dynamic climate allows the temperature to fluctuate within the wide range from minimum to ventilation set point, but to ensure a reliable development of the plants an average temperature of 18 °C was used in all treatments. The climate strategy reached the predetermined average temperature January to March and an overshoot was seen in March to May. The lowest energy use was found in the 15 °C 80% photosynthesis climate.

The production time of the plants (time to flowering) did not differ between the treatments. The plants responded positively in terms of dry weight accumulation to dynamic climates even though the differences were small and in many cases not significant. The results indicate, that using a combination of a dynamic climate control based on photosynthesis with an average temperature control can yield a significant energy saving, but also plants with improved external quality.

INTRODUCTION

In the past decades attempts have been made to produce pot plants in dynamic environments based on models for plant growth and gas exchange (Liu et al., 1997). It is well known that Photosynthetic Photon Flux Density (PPFD), temperature, and CO_2 concentration affect dry weight production. It has been suggested that the relation between the light integral and thermal energy (24-h temperature) could be used to describe the combined effects of temperature and PPFD on dry matter production (Liu and Heins, 1997). While irradiance and CO_2 concentration drives photosynthesis and thereby dry weight gain, the temperature controls the development rate and thus the timing of the crops.

Applying CO_2 increases plant photosynthesis (Heins et al., 1986; Mortensen, 1984; Ottosen and Mentz, 2000), which is linked to the general shape of the response of leaf photosynthesis to intracellular CO_2 concentration, which reaches a plateau at high CO_2 concentration (e.g. Harley and Sharkey, 1991). A positive interaction was found when CO_2 concentration and temperature were adjusted to PPFD in a dynamic photosynthesis based environment (Heins et al., 1986).

An energy minimising and daylight dependent climate control system IntelliGrow has been developed for production of pot plants (Aaslyng et al., 2003). The basic principle is simple, as temperature and CO_2 concentration are regulated according to actual PPFD based on photosynthesis models, thus utilizing the potential free energy generated by the sun and allowing the temperature and CO_2 set points to raise considerably compared to a traditional climate control. Furthermore the span between maximum and minimum temperature might be very large but useful both in ornamentals and vegetables (Ottosen et al., 2003). The damages due to the high temperatures seem to be limited perhaps due to an alleviating effect of elevated CO_2 (Aloni et al., 2001). However in some situations the low temperature regimes resulted in an energy saving of up to 40%, but with an unacceptable extension of the production time, especially in species of tropical origin. The temperate species only showed a delay at very low light levels during mid-winter causing the overall day temperature to be low during a longer period.

The objective of this research was to evaluate the effect of combining dynamic climate control strategies that decreases the energy use, with a mean temperature control strategy on production time and plant quality.

MATERIALS AND METHODS

The dynamic climate control was designed as an add-on to a standard environmental control computer (ECC) (DGT-Volmatic, LCC1200) and were integrated through the BipsArch application interface (Aaslyng et al., 2004). In the dynamic treatments set points for CO_2 and temperature were calculated using a photosynthesis model (Hansen et al., 1996), from which the system generated a two-dimensional array of photosynthesis rates as a function of a range of selected temperatures and CO_2 concentrations at the measured PPFD. The array was calculated from a lower (15 °C) to a higher (30 °C) temperature limit in steps of 1 °C, and from a lower (500 ppm) to a higher (1200 ppm) CO_2 concentration limit. The maximum potential photosynthesis at any given level of PPFD was defined as 100% optimisation.

The experiments included six climate strategies (Table 1) in six greenhouse compartments of 130 m^2 bench areas each. Four used dynamic controls optimized to 80% or 90% combined with a base temperature of 15 or 17 °C. The dynamic climates allow the temperature to fluctuate within a wide range. A 100% optimization would require potentially high energy and CO_2 use. Therefore the lower optimizations (80% and 90%) were used. The photosynthesis models versus set points for temperatures and CO_2 at 80, 90 and 100% are illustrated in Figure 1 and 2. The CO_2 level for the dynamic climates could under low irradiance conditions be lower than a standard and in combination with longer periods of closed vents thus the overall CO_2 consumption might not necessarily exceed the traditional use of CO_2 with fixed CO_2 set points irrespective of temperature.

To ensure a reliable development of the plants an average temperature of 18 °C (obtained over five days) was used in all treatments. However, if the average temperature increased beyond the set point due to the natural heating of the greenhouses no additional ventilation took place to lower the mean temperature. Furthermore a non-forced morning drop of up 4 °C potentially allowed to the temperature to decrease to 12 or 14 °C. Additionally we had a reference climate of 18°C day and 17 °C night and a non-dynamic climate control aiming at a mean temperature of 18°C using the climate computer (Table 1). CO_2 was supplied as liquid CO_2.

Plants of three species were delivered in weeks 2, 4, 13, and 15 (Table 2) from commercial nurseries as newly potted plants in their final pot size and distributed on benches with individual water and nutrient supply. Only one plant species was used per bench. A group of 100 plants in the middle of the bench surrounded by at least two rows of plants were used for measurements of growth and development. During the experiments, plants were harvested every third week for dry weight measurements. The production time was recorded by counting plants regarded as saleable three times a week.

When plants were saleable, the number of open flowers and buds and the measured height of the plant to leaves and flowers was recorded.

The statistical analysis was made using SAS and the Mann-Whitney ranking. Different lettering indicates significant difference at 5 % level.

RESULTS AND DISCUSSION

A selection of the data is presented to give an idea of the general trends in the results. The results of *Campanula* from the first spring trial are shown in Table 3. The standard (Std18/17) had the lowest dry weight and number of buds and flowers, while there was no significant difference between the other treatments. The production time varied 3 days, which just might reflect the fact that we only recorded plants three times a week. The mean temperature varied less than 0.5 °C between the treatments, but the energy use was 82% in the 80F15Avg18 treatments compared to the standard climate.

The results from the same species in March to May production (Table 4) showed roughly the same pattern with the smallest plants and the lowest number of flowers in the standard climate. The production time varied between 40 and 42 days and the mean temperature was slightly higher than the set point (19.6-20.6 °C) because we did not attempt to cool the greenhouses additionally by lowering the ventilation set points. The results in terms of energy saving showed a decrease of energy in the dynamic climates, both when using 15 °C and 17 °C as base temperature.

The results from *Primula* showed no difference in the production time (59 days, Table 5), however this was much shorter than expected based on the initial information from the supplier of plants. The difference in plant performance was not obvious; although the standard climate had slightly more flowers, there was no difference in terms of plant size. The energy saving potential was as high as 34%. There were no negative effects on flower colour when estimated by visual inspection, which had been expected due to the high day temperatures. The effect was rather the opposite on the blue flowers.

Argyranthemum was affected in terms of plant size by the dynamic climate control (Table 6), although less chemical growth regulators were required compared to what is traditionally used in this species. However, there were significantly more flowers in the standard climate.

Research concerning energy saving have had temperature integration over various time horizons as a focal point (e.g. Körner and Challa, 2004, Rijsdijk and Vogelezang 2000) confirming the importance of the mean temperature for scheduling. However, combining the temperature integration with the use of a dynamic climate, created by a large span in the diurnal temperatures due to the dynamic nature of the climate control system, has no negative effects on the plants, but saves energy. The potential low night temperatures might have a reducing effect on elongation, while high CO_2 levels are known to alleviate possible negative effects of relative high temperatures. We conclude that by using a combination of a dynamic climate based on the response of photosynthesis on the climate to control the carbon gain, and an average temperature control to control production time, it is possible to obtain not only a significant energy saving without technical investments in the greenhouse, but also plants with high external quality.

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Tables

Table 1. Description of climate control strategies.

Abbreviation	Climate treatment
Std18/17	Standard climate, 18 °C day/17 °C night temperature, ventilation at 22°C [1)]
Avg18	24 hrs 18 °C mean temperature using the DGT-Volmatic climate computer control, ventilation at 22°C [1)]
90F17Avg18	90% of potential photosynthesis (related to PPFD), minimum base temperature 17°C, 2 hrs morning drop after sunrise to 14 °C [2)]
90F15Avg18	90% of potential photosynthesis (related to PPFD), minimum base temperature 15°C, 2 hrs morning drop after sunrise to 12 °C [2)]
80F17Avg18	80% of potential photosynthesis (related to PPFD), minimum base temperature 17°C, 2 hrs morning drop after sunrise to 14 °C [2)]
80F15Avg18	80% of potential photosynthesis (related to PPFD), minimum base temperature 15°C, 2 hrs morning drop after sunrise to 12 °C [2)]

[1)] 600 ppm CO_2 in light

[2)] CO_2 optimisation according to photosynthesis models in the range 500 – 1200 ppm in light

Table 2. Plant species used in the experiment of spring 2003.

Species	**Production started**
Campanula carpatica ‘Blue Clips’	Week 2, 4, 13 and 15
Primula obconica ‘Touch me’	Week 2 and 4
Argyrathemum frutescens ‘Dana’	Week 2, 4, 13 and 15

Table 3. Effects of the climate control strategies on *Campanula carpatica* ‘Blue Clips’, grown to flowering from January to March 2003 with chemical growth regulation. Different lettering indicates significant different at the 5% level.

Treatment (Abbreviations in Table 1)	Production time (days)	Mean Temperature (°C)	Mean PPFD (µmol $m^{-2} s^{-1}$)	Mean CO_2 concentration (ppm)	% of energy of Std18/17	Mean dry weight (g)	Mean number of buds and flowers	Mean height to upper leaves (mm)	Mean hight to flowers (mm)
Std18/17	53	18.0 b	75 a	625 c	100	5.8 b	66 b	94 b	106 b
Avg18	53	18.1 ab	76 a	655 ab	103	6.3 ab	72 ab	97 ab	109 b
90F17Avg18	53	18.1 ab	72 a	645 abc	123	6.7 ab	71 ab	101 a	121 a
90F15Avg18	53	18.4 a	74 a	664 a	97	6.8 a	75 ab	97 ab	109 b
80F17Avg18	56	18.0 b	79 a	637 bc	99	7.0 a	70 ab	98 ab	112 ab
80F15Avg18	56	18.2 ab	75 a	642 abc	82	6.7 ab	79 a	99 ab	117 ab

Table 4. Effects of the climate control strategies on *Campanula carpatica* ‘Blue Clips’, grown to flowering from March to May 2003 with chemical growth regulation. Different lettering indicates significant different at the 5% level.

Treatment (Abbreviations in Table 1)	Production time (days)	Mean Temperature (°C)	Mean PPFD (µmol $m^{-2} s^{-1}$)	Mean CO_2 concentration (ppm)	% of energy of Std18/17	Mean dry weight (g)	Mean number of buds and flowers	Mean height to upper leaves (mm)	Mean hight to flowers (mm)
Std18/17	42	19.6 a	191 a	585 b	100	13.9 b	182 ab	104 c	122 d
Avg18	40	20.2 a	201 a	711 a	99	15.7 a	172 b	114 b	135 abc
90F17Avg18	40	20.1 a	194 a	719 a	82	15.7 a	200 a	121 a	144 a
90F15Avg18	40	20.4 a	207 a	723 a	89	16.5 a	174 b	113 b	125 dc
80F17Avg18	42	20.2 a	202 a	702 a	77	16.5 a	202 a	115 b	131 bcd
80F15Avg18	42	20.2 a	193 a	689 a	88	16.3 a	200 a	113 b	139 ab

Table 5. Effects of the climate control strategies of *Primula obconica* ‘Touch me’, grown to flowering from January to March 2003 without chemical growth regulation. Different lettering indicates significant difference at the 5% level.

Treatment (Abbreviations in Table 1)	Production time (days)	Mean Temperature (°C)	Mean PPFD (µmol m^{-2} s^{-1})	Mean CO_2 concentration (ppm)	% of energy of Std18/17	Mean dry weight (g)	Mean number of buds and flowers	Mean hight to flowers (mm)
Std18/17	59	18.0 a	76 a	626 c	100	10.7 ab	33 abc	153 a
Avg18	59	18.1 a	77 a	661 ab	114	11.3 ab	38 a	158 a
90F17Avg18	59	18.1 a	73 a	653 ab	95	12.0 a	36 ab	149 a
90F15Avg18	59	18.3 a	75 a	670 a	95	10.9 ab	28 bc	139 a
80F17Avg18	59	18.0 a	80 a	642 bc	97	11.4 ab	26 c	146 a
80F15Avg18	59	18.2 a	76 a	646 abc	66	10.5 b	30 abc	156 a

Table 6. Effects of the climate control strategies of *Argyranthemum frutescens* ‘Dana’, grown to flowering from March to May 2003 with chemical growth regulation. Different lettering indicates significant difference at the 5% level.

Treatment (Abbreviations in Table 1)	Production time (days)	Mean Temperature (°C)	Mean PPFD (µmol m^{-2} s^{-1})	Mean CO_2 concentration (ppm)	% of energy of Std18/17	Mean dry weight (g)	Mean number of buds and flowers	Mean hight to flowers (mm)
Std18/17	36	20.1 a	212 a	611 b	100	7.4 b	105 a	170 b
Avg18	36	20.6 a	228 a	702 a	77	7.2 bcd	90 bcd	181 ab
90F17Avg18	36	20.7 a	219 a	697 a	77	6.6 d	92 d	159 c
90F15Avg18	36	20.9 a	238 a	704 a	83	7.0 cd	79 bc	175 b
80F17Avg18	37	20.7 a	237 a	678 a	76	8.4 a	96 b	174 b
80F15Avg18	37	20.6 a	217 a	673 a	75	7.5 bc	85 cd	184 a

Figures

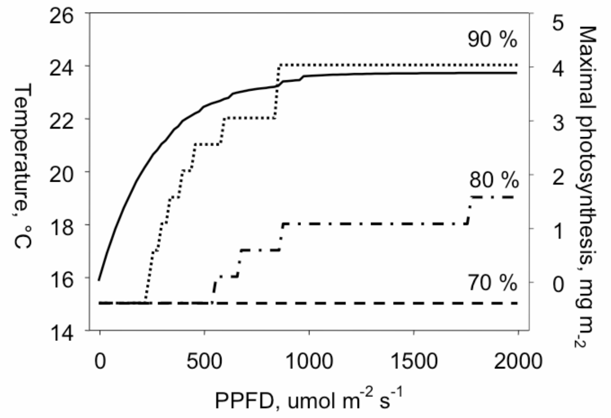

Fig. 1. Model of photosynthesis responses and IntelliGrows regulation of the temperature (dashed lines and left y axis) at different optimization levels. The thin line shows the photosynthesis model response (right y axis).

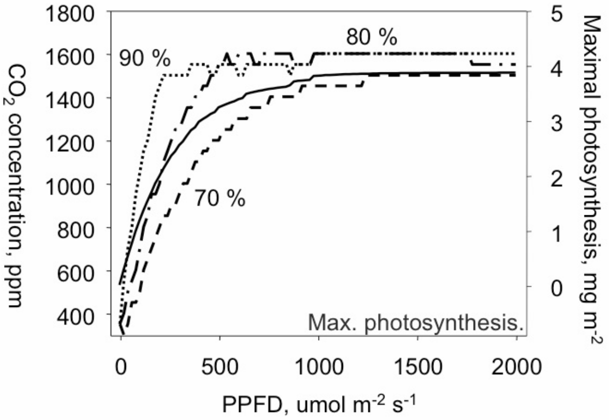

Fig. 2. Model of photosynthesis responses and IntelliGrows regulation of CO_2 concentration (dashed lines and left y axis) at different optimization levels. In reality the CO_2 demand never exceeded 1200 ppm. The thin line shows the photosynthesis model response (right y axis).