THE UNIVERSITY OF
WARWICK

University of Warwick institutional repository

This paper is made available online in accordance with publisher policies. Please scroll down to view the document itself. Please refer to the repository record for this item and our policy information available from the repository home page for further information.

To see the final version of this paper please visit the publisher's website. Access to the published version may require a subscription.

Author(s): S.R. ADAMS, V.M. VALDÉS and D. FULLER

Article Title: The effects of day and night temperature on Chrysanthemum morifolium: investigating the safe limits for temperature integration
Year of publication: 2009
Link to published version :
http://www.jhortscib.org/Vol84/84_6/6.htm

Publisher statement: None

The effects of day and night temperature on *Chrysanthemum morifolium*; investigating the safe limits for temperature integration

By S. R. ADAMS*, V. M. VALDÉS and D. FULLER

Warwick HRI, The University of Warwick, Wellesbourne, Warwick, CV35 9EF, UK.

(e-mail: steven.adams@warwick.ac.uk)

* Author for correspondence.

Word count: 3946
Number of Tables: 1
Number of Figures: 3

SUMMARY

The impact of day and night temperatures on pot chrysanthemums (cultivars Covington and Irvine) was assessed by exposing cuttings stuck in weeks 39, 44 and 49 to different temperature regimes in short days. Glasshouse heating set-points of 12, 15, 18 and 21°C were used during the day, with venting at 2°C above these set-points. Night temperatures were then automatically manipulated to ensure that all of the treatments achieved similar mean diurnal temperatures. Plants were grown according to commercial practice and the experiment was repeated over two years. Increasing the day temperature from around 19 to 21°C and compensating by reducing the night temperature did not have a significant impact on flowering time, although plant height was increased. This suggests that a temperature integration strategy which involves higher vent temperatures and exploiting solar gain to give higher than normal day temperatures should have minimal impact on crop scheduling. However, lowering the day temperature to around 16°C and compensating with a warmer night delayed flowering by up to two weeks. Therefore, a strategy whereby, in winter, more heat is added at night under a thermally efficient blackout screen may result in flowering delays. Transfers between the temperature regimes showed that the delays were proportional to the amount of time spent in a low-day regime; plants flowered at the same time irrespective of whether they were transferred on a 1, 2 or 4 week cycle.

Flowering time is generally regarded to be a function of mean diurnal temperature, with no special effects of day (D) or night (N) temperature. While Cathey (1954) concluded that night temperature had a greater effect on flowering time than day temperature in chrysanthemum, Cockshull *et al*. (1981) pointed out that Cathey had not taken into account the fact that the night (15 h) was longer than the day (9 h) when calculating average temperatures. Cockshull *et al*. (1981) reanalysed Cathey's data and concluded that flowering was in fact correlated with the average temperature and that night temperature had no special influence. This conclusion was supported (for most cultivars) by their own experiments in which chrysanthemums were grown at temperatures between 10 and 20°C with some treatments having different day and night temperature combinations giving the same average temperature.

The optimum temperature for flowering in chrysanthemum is in the range 18 to 21°C (de Jong, 1978, 1989; de Lint and Heij, 1987; Karlsson *et al*., 1989; Hidén and Larsen, 1994; Adams *et al*., 1998) and so the simple response to average temperature can be expected to break down when a combination of sub- and supra-optimal temperatures are used (Karlsson *et al*., 1989). The data of Cathey (1954) and Karlsson *et al*. (1989) were reanalysed, together with other published data (de Jong, 1978; de Lint and Heij, 1987), by Pearson *et al*. (1993). They concluded that the rate of progress to flowering (1/days to flower) in chrysanthemum increases linearly with temperature up to an optimum and then decreases linearly with increasing supra-optimal temperatures. They also included a linear response to photosynthetic photon flux density (PPFD) as higher light integrals have been shown to hasten both flower initiation and development (Carvalho and Heuvelink, 2001; van der Ploeg and Heuvelink, 2006). The simple model presented by Pearson *et al*. (1993) was able to adequately describe all of the data sets, providing further evidence that there are no special effects of day or night

temperature. Hidén and Larson (1994) were unable to detect a true linear response between mean temperature and the rate of progress to flowering, and instead used a double exponential equation to model the relationship between temperature and flowering time, again without any special effects of day or night temperature.

The approach taken by Pearson *et al.* (1993) intrinsically assumes that plants respond to the instantaneous temperature. Langton and Horridge (2006) showed that growing at 24D/14N (D and N = 12 h) delayed flowering of chrysanthemum by on average 4 days when compared with 19°C continuously; however, the delay was 3 days less than might have been expected based on the mean of the continuous 14 and 24°C treatments. Cycling between 14 and 24°C over 2 or 14 day cycles gave greater delays than the 24D/14N treatment, although flowering was still slightly faster than might have been expected based on the continuous 14 and 24°C treatments. This suggests that plants do not respond simply to instantaneous temperature or to the long-term average, rather to something in between.

With recent increases in energy costs and the need to reduce carbon footprints, growers are under increasing pressure to save energy. One of the approaches that is being adopted is the use of temperature integration where glasshouse temperatures are allowed to fluctuate while achieving similar average temperature. Often this involves raising vent temperatures so that, when there is sufficient solar gain, day temperatures are higher and the associated temperature credits can be used at night or on dull days, thus reducing the heat input. Further savings can be made by reducing the day heating set-points and allowing day temperatures to drop when there is little solar gain. To compensate for these cooler days, more heat is then used at night when blackout screens are in place as this reduces heat losses. Semi-commercial and commercial trials of temperature integration using high vent temperatures have shown little or no flowering delay (Langton *et al.*, 2003). However, the

strategy of using low day temperatures and compensating with higher night temperatures under a blackout or energy screen has not been fully investigated with regards to the impact on crop scheduling or plant quality. This work aims to determine the safe limits of this approach for chrysanthemum.

MATERIALS AND METHODS

Unrooted cuttings of chrysanthemum (*Chrysanthemum morifolium*) cvs. Covington and Irvine obtained from a commercial propagator (Yoder Toddington, Littlehampton, UK) were stuck in weeks 39, 44 and 49 in both 2005 and 2006. Five cuttings, treated with Bumper (prochloraz and propiconazole at a rate of 0.4 ml l^{-1}) to minimise the risk of white rust, were stuck into each 14 cm pot containing an 80% sphagnum peat and 20% bark growing medium. The cuttings were rooted in a glasshouse compartment set to provide a minimum temperature of 18°C (vent 24°C) with bench heating providing a compost temperature of around 21°C. Shade screens were used when the external light level exceeded 350 W m^{-2} (total solar). The cuttings were initially given long days (lit from 22:00 to 03:15) using cyclical (15 min on; 15 min off) tungsten night-break lighting (0.5 W m^{-2} PAR) and were covered with polythene sheeting. The polythene was removed after 9 d and, subsequently, high-pressure sodium lamps were used continuously to provide approximately 13 W m^{-2} (PAR) at plant height. The aerial CO_2 concentration was enriched to 1000 µmol mol^{-1} which ramped down to 350 µmol mol^{-1} between 5 and 10% vent. Plants were sprayed for height control with B-nine (Daminozide) at a rate of 1.0 g l^{-1} after the removal of the polythene.

At the end of propagation (18 days) plants were moved to four 50 m^2 glasshouse compartments where short days were given (12 h d^{-1}). These compartments were set to provide day heating set-points of 12 (12D), 15 (15D), 18 (18D; standard) and 21°C (21D)

5

with venting at 2°C above these set-points. The night temperature set-point in the 18D compartment was 18°C, while the set-points in the other compartments were automatically adjusted so that all the compartments had a similar mean 24 h temperature. The achieved CO_2 concentration in the 12D compartment (set to 1000 µmol mol^{-1}) was entered as a set-point in the other three compartments which had less ventilation, so as to achieve a similar CO_2 concentration in all four compartments. Temperatures and CO_2 concentrations were independently monitored and logged, and data were compared with those recorded using the greenhouse climate control computer. High-pressure sodium lamps were used from 06:00 to 18:00 h (approximately 13 W m^{-2} PAR at plant height) and blackouts were used from 18:00 to 06:00 h with some gapping at night for humidity and temperature control. Humidity control also involved the introduction of minimum pipe and minimum vent temperatures.

The initial density following propagation was 25 pots m^{-2} which was reduced after two weeks to a final spacing of 14.5 pots m^{-2}. Plots were surrounded by guard plants and there were two plots of each cultivar in each compartment. Some plants were transferred regularly from the 12D and 15D compartments to both the 18D and 21D compartments and back again such that they spent 0, 29, 57 or 100% of the time in a low-day temperature regime. Furthermore, these transfers were carried out with 1, 2 or 4 week cycles. Therefore, plants spending 29% of their time in the low-day regime had 2, 4 or 8 days in 12D or 15D followed by 5, 10 or 20 days in either 18D or 21D for the 1, 2 and 4 week cycles, respectively. Six pots from each compartment were used for each transfer combination, and 12 non-transferred pots remained in each compartment (6 in each replicate plot).

Plants were grown on capillary matting and were irrigated via seep hose using a 300 mg l^{-1} N: 26 mg l^{-1} P: 207 mg l^{-1} K feed. All plants were pinched in order to promote branching in line with commercial practice. All plants were sprayed with B-nine (1.5 g l^{-1}) when the new

shoots were approximately 2 cm long. Subsequent applications were applied to plants in all compartments based on height measurements in the 18D compartment using graphical tracking. Pest and disease control strategies followed commercial practice.

The time at which the first flower of each pot reached flowering stage 6 (Cockshull and Hughes, 1972) was recorded. Plants were grown on to the marketable stage (12 flowers per pot having reached stage 6). One plant per pot was then randomly selected to record the height, leaf number, leaf area, shoot fresh weight and shoot dry weight. Data were analysed by ANOVA using Genstat.

RESULTS

The four glasshouse compartments maintained different day and night temperatures but similar mean diurnal temperatures in 2005 and 2006 (Table I). The temperatures tended to be slightly higher in the autumn, at the beginning of each experiment, due to solar gain and high ambient temperatures; this increased the average day temperatures for the week 39 crops. Over the winter period greater and more consistent temperature differences were achieved between day and night. The achieved CO_2 concentrations were similar across the four compartments, although, due to increased ventilation, the week 39 crops had a slightly lower concentration (637 µmol mol^{-1}) compared with the week 44 and 49 crops (725 and 707 µmol mol^{-1}, respectively). The mean PPFD was 9.8, 7.3 and 8.3 mol m^{-2} d^{-1} in 2005, and 8.9, 8.1 and 9.3 mol m^{-2} d^{-1} in 2006, for the crops stuck in weeks 39, 44 and 49, respectively. This may explain why there was a strong interaction between week and year ($P < 0.001$) with the week 39 crop flowering slightly earlier in 2005 and the week 49 crop flowering slightly earlier in 2006.

The different temperature regimes significantly (P < 0.001) affected days to flower stage 6 and the marketable stage for both cultivars. Although all of the compartments achieved similar mean temperatures, flowering was delayed in the low-day regimes, particularly 12D (Figure 1). Plants that were grown at around 21°C during the day and 16°C at night (21D) flowered much quicker than those that were grown at around 16°C during the day and 21°C at night (12D), the only difference being the time at which these apparently sub- and supra-optimal temperatures were given. The delays at 12D tended to be greater for the crops stuck in weeks 44 and 49 as these experienced a greater day/night temperature differential. There was also a significant interaction between year and temperature treatment (P < 0.001) due to the fact that the 12D treatment achieved lower day temperatures in 2005 (Table I).

Transferring plants between 12D and both 18D and 21D, and between 15D and both 18D and 21D, showed that the delay in time to flowering was a linear function (P < 0.001) of the time spent in the low-day regime (Figure 2). There was little evidence of any interaction with the cycle frequency; plants flowered at the same time irrespective of whether they were transferred on a 1, 2 or 4 week cycle.

For both cultivars there were significant effects of year, sticking week and temperature regime, on plant height (P < 0.001) when plants were measured at marketing. Due to the ambient conditions changing there was also a significant interaction between year and sticking week. In both years the tallest plants were typically from the 21D regime while the shortest plants were from the 15D regime (Figure 3). Plants grown at 12D were taller than those from 15D (P < 0.05), probably due the delay in marketing. The differences in day and night temperature also affected (P < 0.01) the total number of leaves, leaf areas and shoot dry

8

weights; plants grown in 12D tended to have an increased leaf number, leaf area and dry weight at marketing (Figure 3).

DISCUSSION

The results support previous observations that temperature integration with higher vent temperatures need not result in deleterious flowering delays (Langton *et al*., 2003), as raising the day temperature slightly and compensating with lower nights had minimal impact on flowering time. However, greater care will clearly be needed if adopting a strategy whereby day heating set-points are reduced, and increased night temperatures are used under screens to compensate for days with little solar gain when low day temperatures are achieved. However, our low-day regimes were achieved by actively venting during the day (so as to achieve larger and more consistent day – night temperature differences), and so the temperature differences, and therefore delays, achieved in commercial growing would rarely be as extreme as in the trials reported here.

When adopting a temperature integration strategy with higher vent temperatures, there is often a compromise between energy saving and plant quality. Here the plants grown with a high-day and low-night temperature regime were taller, as might be expected due to longer internodes (Carvalho *et al*., 2002). Whereas the low-day and high-night regimes did not appear to be detrimental with regards to plant quality. These regimes tended to produce shorter and more compact plants which could be beneficial in reducing the need for plant growth regulators. However, this was not the case in the 12D treatment at marketing, presumably because the extended growing period more than compensated for any temperature effect on stem extension growth. This treatment also tended to have a higher total leaf number

and area and greater dry weight at marketing, again probably due to the flowering delays and longer growing time.

Mean temperature is generally considered to determine flowering time in chrysanthemum (Pearson *et al*., 1993). However, here we have shown marked delays in flowering through the use of low-day and high-night regimes, even though the mean temperature was similar to that of the control. These delays cannot be simply due to averaging sub- and supra-optimal temperatures (Pearson *et al*., 1993; Langton and Horridge, 2006) because the 21D treatment (which achieved around 21D/16N) would have been expected to give a similar delay to 12D treatment (which achieved around 16D/21N) and this was not found to be the case. While both cultivars (Irvine and Covington) showed delayed flowering in low-day and high-night regimes, the daylit controlled environment experiments of Cockshull *et al*. (1981) would suggest that cultivars vary in this regard. While many of the cultivars they examined appeared to respond to mean temperature, some cultivars (Hurricane and Elegance) were delayed when plants were grown at 10D/20N as compared with 20D/10N or 15D/15N (all with 12 h days and nights).

The reason for the difference in response to day and night temperature is unclear. Low day temperatures may affect photosynthesis (Warren and Dreyer, 2006) and, therefore, assimilate availability. This in turn may affect flowering, given the importance of light integral (assimilates) in determining flowering time (Pearson *et al*., 1993). However, here the dry weight data would suggest that any reduction in photosynthesis due to low day temperatures was minimal within the temperature range used. This would tend to cast doubt on this being the cause of delayed flowering in the low-day temperature regimes, although it is possible that any reduction in photosynthesis and therefore dry weight was masked due to the flowering delays.

10

Langton and Horridge (2006) showed that chrysanthemums flowered earlier when grown in a 24D/14N regime as compared with alternating between continuous 14 and 24°C on 2 or 14 day cycles. They suggested that thermal inertia may provide a possible explanation, as more frequent temperature changes would result in the meristem spending less time at the extreme temperatures. Nevertheless they stated that tissue temperatures generally reach equilibrium fairly quickly after a temperature change and suggested that some other factor is probably responsible. Similarly in this experiment it seems unlikely that the average plant or apex temperatures will have differed greatly as a result of the different day and night temperature treatments.

Perhaps a more likely explanation for delayed flowering in low-day high-night regimes would be a different temperature response during the day and night. While there is little evidence to suggest a differential day or night response on the effect of temperature on the rates of progress to flowering (Pearson *et al*., 1993), it is possible that the optimum temperature might shift. Adams *et al*. (1997) showed that in pansy, mean daily light integral could influence the optimum temperature for flowering with the optimum temperature decreasing linearly (from 21.3°C) as light integral fell below 3.4 MJ m^{-2} d^{-1}. If the optimum temperature for flowering in some chrysanthemum cultivars was lower at night than during the day, this could explain the responses to temperature observed here. However, further work would be needed to prove this; in this experiment all compartments had similar mean temperatures and so day and night conditions were correlated. A shift in optimum temperature may not have been reported previously because of cultivar differences, and because small differences in optimum temperature are unlikely to be noted in experiments where the temperature differences between treatments are relatively large or where few supra-optimal regimes are included.

REFERENCES

ADAMS, S. R., PEARSON, S. and HADLEY, P. (1997). The effects of temperature, photoperiod and light integral on the time to flowering of pansy cv. Universal Violet (*Viola x wittrockiana* Gams.). *Annals of Botany,* **80**, 107-112.

ADAMS, S. R., PEARSON, S. and HADLEY, P. (1998). The effect of temperature on inflorescence initiation and subsequent development in chrysanthemum cv. 'Snowdon' (*Chrysanthemum* x *morifolium* Ramat.). *Scientia Horticulturae*, **77,** 59-72.

CATHEY, H. M. (1954). Chrysanthemum temperature study. C. The effect of night, day and mean temperature upon the flowering of *Chrysanthemum morifolium. Proceedings of the American Society for Horticultural Science*, **64,** 499-502.

CARVALHO, S. M. P. and HEUVELINK, E. 2001. Influence of greenhouse climate and plant density on external quality of chrysanthemum (*Dendranthema grandiflorum* (Ramat.) Kitamura): First steps towards a quality model. *Journal of Horticultural Science & Biotechnology*, **76**, 249-258.

CARVALHO, S. M. P., HEUVELINK, E., CASCAIS, R. and VAN KOOTEN, O. (2002). Effect of day and night temperature on internode and stem length in chrysanthemum: is everything explained by DIF? *Annals of Botany*, **90**, 111-118.

COCKSHULL, K. E. and HUGHES, A. P. (1972). Flower formation in *Chrysanthemum morifolium*: the influence of light level. *Journal of Horticultural Science*, **47,** 113-127.

COCKSHULL, K. E., HAND, D. W. and LANGTON, F. A. (1981). The effects of day and night temperature on flower initiation and development in chrysanthemum. *Acta Horticulturae*, **125**, 101-110.

DE JONG, J. (1978). Selection for wide temperature adaptation in *Chrysanthemum morifolium* (Ramat.) Hemsl. *Netherlands Journal of Agricultural Science*, **26,** 110-118.

DE JONG, J. (1989). Analysis of components controlling early flowering of chrysanthemum at low temperature. *Euphytica,* **40,** 121-126.

DE LINT, P. J. A. L. and HEIJ, G. (1987). Effects of day and night temperature on growth and flowering of chrysanthemum. *Acta Horticulturae*, **197,** 53-61.

HIDÉN, C. and LARSEN, R. U. (1994). Predicting flower development in greenhouse grown chrysanthemum. *Scientia Horticulturae*, **58,** 123-138.

KARLSSON, M. G., HEINS, R. D., ERWIN, J. E. and BERGHAGE, R. D. (1989). Development rate during four phases of chrysanthemum growth as determined by preceding and prevailing temperatures. *Journal of the American Society for Horticultural Science,* **114,** 234-240.

LANGTON, F. A., CLARKE, I. P. and HAMER, P. J. C. (2003). Energy-saving strategies. *Grower*, **139**, 14-15.

LANGTON, F. A. and HORRIDGE, J.S. (2006). The effects of averaging sub- and supra-optimal temperatures on the flowering of *Chrysanthemum morifolium*. *Journal of Horticultural Science & Biotechnology*, **81**, 335-340.

PEARSON, S., HADLEY, P. and WHELDON, A. E. (1993). A re-analysis of the effects of temperature and irradiance on time to flowering in chrysanthemum (*Dendranthema grandiflora*). *Journal of Horticultural Science,* **68,** 89-97.

VAN DER PLOEG, A. and HEUVELINK, E. 2006. The influence of temperature on growth and development of chrysanthemum cultivars: a review. *Journal of Horticultural Science & Biotechnology*, **81**, 174-182.

WARREN, C. R. and DREYER E. 2006. Temperature response of photosynthesis and internal conductance to CO_2: results from two independent approaches. *Journal of Experimental Botany*, **57**, 3057-3067.

Table I. *Achieved average day (06:00 to 18:00), night and mean diurnal temperatures recorded using independent sensors for plants stuck in weeks 39, 44 and 49.*

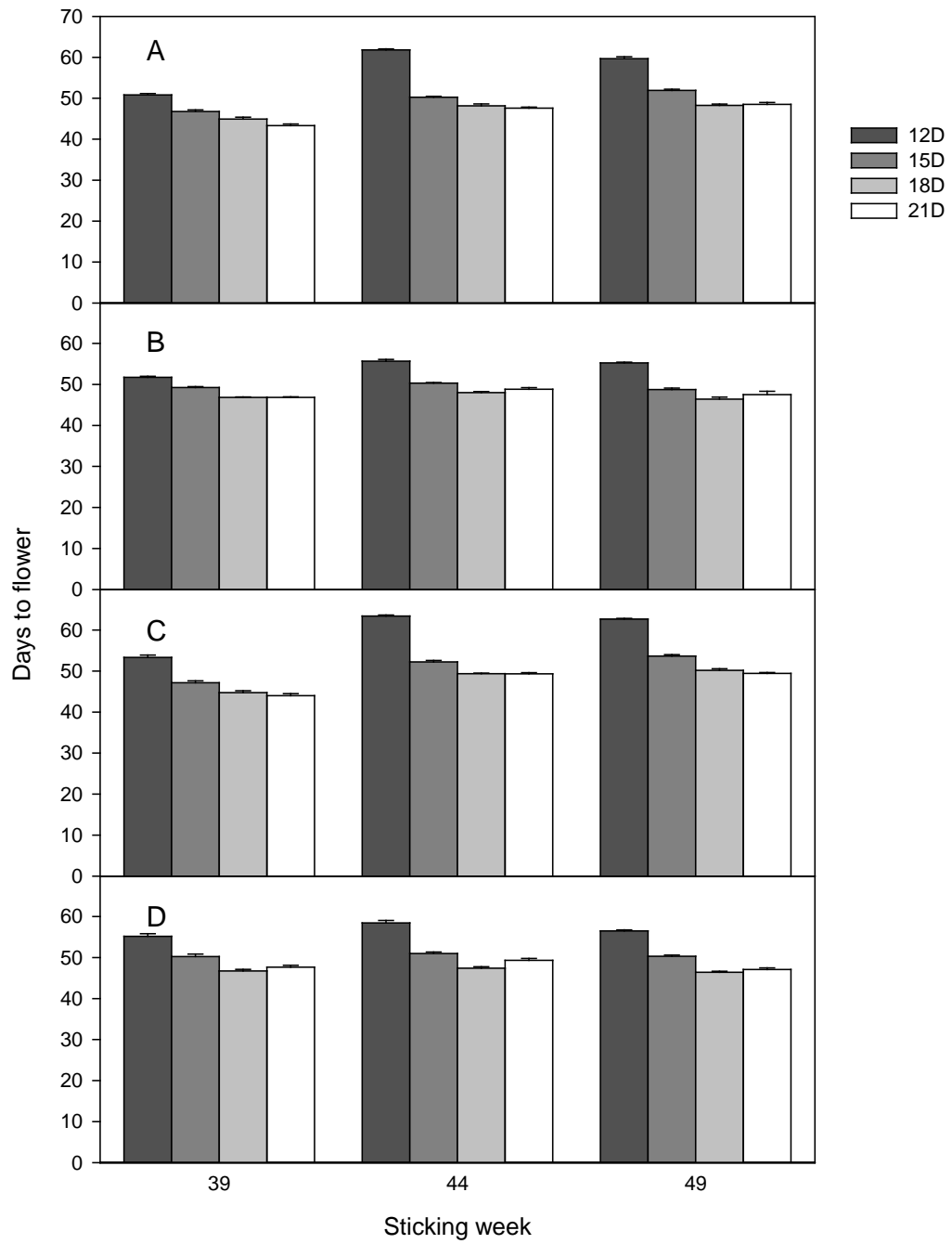|	Week 39			Week 44			Week 49		
	Day	Night	24 h	Day	Night	24 h	Day	Night	24 h
2005									
12D	16.7	20.5	18.6	15.3	21.1	18.2	15.4	21.4	18.4
15D	18.1	19.5	18.8	17.3	19.5	18.4	17.4	19.6	18.5
18D	19.2	18.2	18.7	18.4	18.1	18.3	18.6	18.2	18.4
21D	21.6	16.4	19.0	21.1	15.9	18.5	21.3	16.0	18.6
2006									
12D	16.9	20.5	18.7	16.1	20.9	18.5	16.1	21.0	18.6
15D	17.9	19.1	18.5	17.3	19.2	18.2	17.4	19.3	18.3
18D	19.4	18.2	18.8	18.8	18.1	18.5	19.1	18.1	18.6
21D	21.4	16.0	18.7	21.0	15.7	18.4	21.1	15.8	18.4

FIG. 1

The effect of temperature regime on the number of short days to flowering (stage 6) of Covington in 2005 (Plate A), Covington in 2006 (Plate B), Irvine in 2005 (Plate C), and Irvine on 2006 (Plate D). Error bars indicate ± 1 SEM.
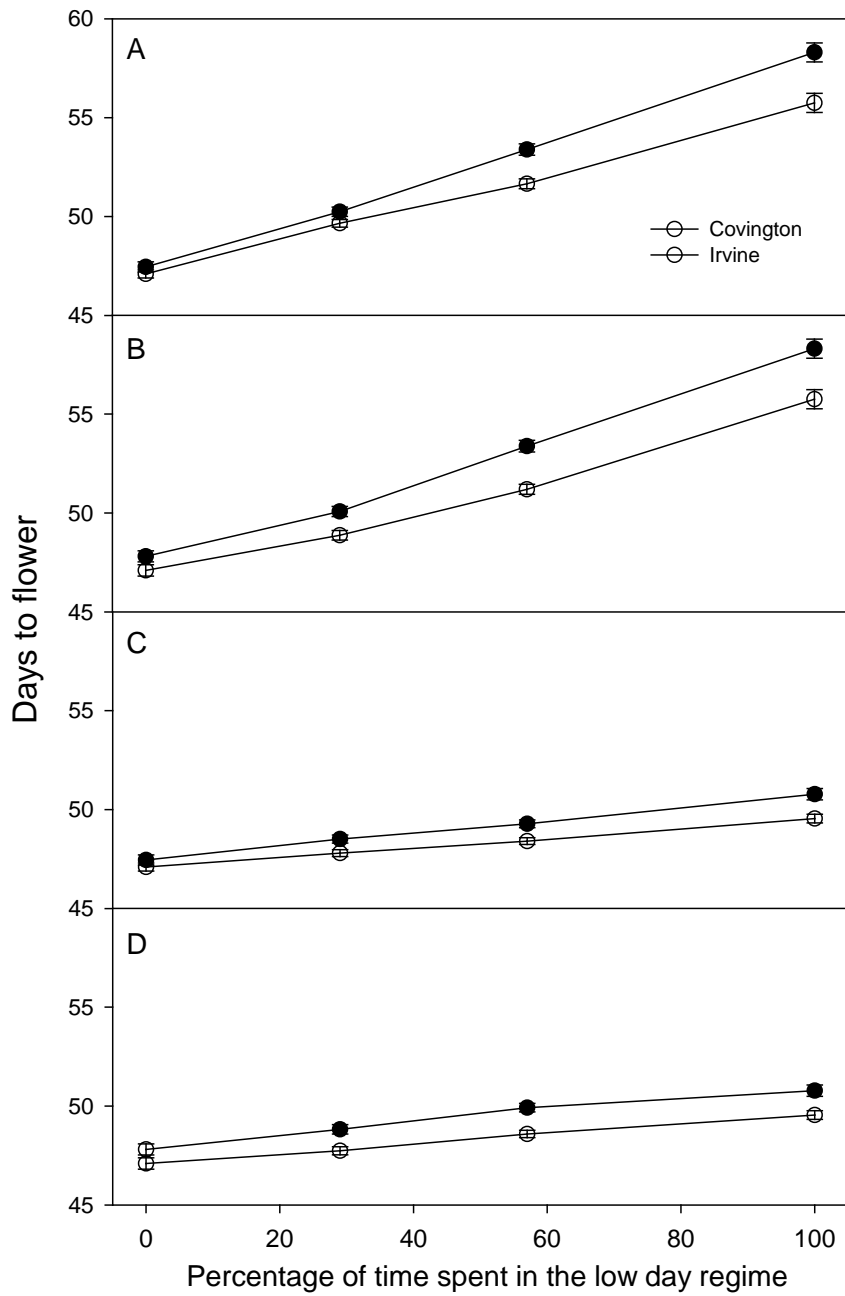
FIG. 2

The effect of transferring plants from 12D to 18D (Plate A), 12D to 21D (Plate B), 15D to 18D (Plate C), and 15D to 21D (Plate D) on the number of short days to flowering (stage 6). The data are the average values for both years and all sticking weeks. Error bars indicate ± 1 SEM.
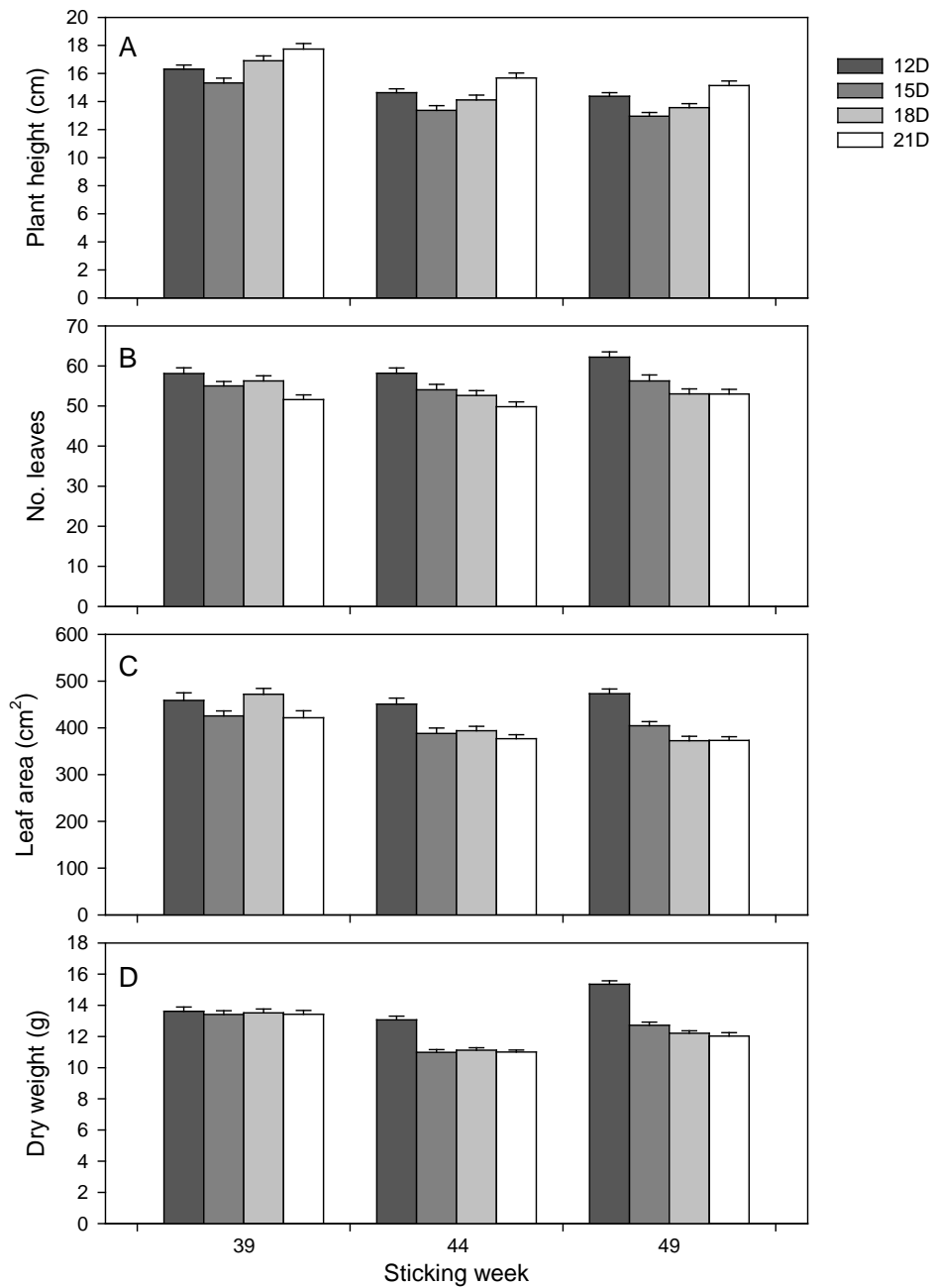
FIG. 3

The effect of temperature regime on plant height (Plate A), total leaf number (Plate B), leaf area (Plate C) and shoot dry weight (Plate D). The data are the average values for both cultivars and years. Error bars indicate ± 1 SEM.