Project Number: PC74a

Title: Bedding Plants: Effects of photo-thermal environments on growth, development and flowering.

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CONTENTS

GROWER APPLICATION AND KEY-FINDINGS

The objectives of this study were to develop sowing date schedules for 6 of the key bedding plant species; antirrhinum, salvia, marigold, impatiens, petunia and geranium. This study extends previous work on scheduling reported previously by Pearson *et al.,* (1995) by extending the species and variety range covered. Schedules have been developed by producing quantitative models of the effects of temperature, photoperiod and light integral on the time to flowering of each of the species. These models were calibrated by growing crops at a range of different combinations of temperatures, photoperiods and light integrals; the latter achieved by using different sowing dates and shade cloth treatments. In all over 750 different batches of bedding plants were grown. This report contains sowing date schedules developed for each of the species and varieties examined.

A full quantitative description of factors affecting flowering of these crops should help realise the following commercial benefits;

I) Improved plant scheduling to reduce product wastage.
II) Identification of optimum temperature for plant growth.
III) The ability to forecast and manipulate maturity dates to meet contractual commitments or to identify marketing opportunities.
IV) Ability to maximise space use efficiency, through the ability to accurately forecast production.
V) The models can be applied to identify the most economic growing regimes to produce the crops.

The key findings for each crop were;

- **Antirrhinum**: The key factors affecting time to flowering of this species were temperature and photoperiod. Cool temperature delayed time to flowering considerably, thus plants of Coronette Yellow required 120 days to flower at 12°C compared to 70 days at 25°C. Long photoperiods also hastened time to flowering, but this effect was weak compared to the temperature response, since increasing photoperiod from 9 to $15hd^{-1}$ only reduced time to flowering by about 18 days. However, short photoperiods led to an increase in leaf production and final plant height at flowering. Plant height at flowering was also reduced at the higher temperatures, this was attributable to lower leaf production and the shorter time required for flowering. These results suggest that the use of day length extension lighting may have potential as a means to limit growth and plant height, via the reduction in leaf production. Though further work is required to confirm this and the economic benefits of any such treatment.

- **Salvia**: Time to flowering in two varieties of salvia Sizzler Red and Flamex was found to be dependent on temperature and photoperiod. Time to flowering decreased curvilinearly as temperature increased, such that for Sizzler Red flowering occurred after 100 days at 12^0C compared to 60 days at 25°C. A daylength of $15hd^{-1}$ reduced time to flowering by 10 days compared to a $9hd^{-1}$ daylength. Sizzler Red flowered, on average 7 days earlier than Flamex at all temperatures. Sowing date schedules were developed for both varieties. Plant height at flowering increased linearly with temperature. Growth was retarded considerably by low growing temperatures (<14°C).

- **Marigold:** Time to flowering of two varieties of marigold cv. Aurora Fire and Yellow Boy was found to be largely dependent on temperature and the daily light integral. Thus, at a temperature of 12°C plants of cv. Yellow Boy required 62 days to flowering compared to 42 days at 25°C. The response to light integral was also marked, such that at light levels equivalent to a January day (2 $MJm^{-2}d^{-1}$; total solar radiation) the plants required 100 days for flowering compared to 50 days in light levels equivalent to those received inside the glasshouse on a May day (10 $MJm^{-2}d^{-1}$). There was a suggestion that at very high temperatures short days were required for flowering, since during the summer plants grown in natural long days and high temperatures (>22°C) did not flower. The reduced time to flowering at high temperatures was, however, due to the detriment of final quality, since plant height increased linearly with temperature. Desired temperatures for the production of marigold were between 16 to 20°C. Sowing date schedules and models to predict time to flowering in any set of environmental conditions are presented.

- **Impatiens:** Factors affecting quality of impatiens were described in detail in the previous report. Here the effects of photoperiod, temperature and light integral on time to flowering were investigated. Impatiens were found to be day-neutral, however, time to flowering was highly dependent on light integral and temperature. The temperature response was quite marked, such that at 12°C plants required 120 days to flower compared to 55 days at 20°C. The response to light integral was also considerable, such that the to flowering was halved from 120 to 60 days as light integral increased from 3 to 15$MJm^{-2}d^{-1}$. This high sensitivity to temperature and light integral may partially explain why Impatiens have a notorious reputation for premature or delayed flowering, since small changes to environmental conditions will have a considerable effect on time to flowering. Sowing date schedules were developed and presented for two varieties of impatiens; Super Elfin Blue Pearl and Red Star.

- **Petunia:** The effects of temperature and photoperiod on the growth and quality of petunia were described in the previous report. Here, flowering responses of three varieties of petunia were examined. The data showed that all the varieties were similarity responsive to long photoperiods (earlier flowering) and high temperatures. Photoperiods of 15hd^{-1} advanced time to flowering by 22 days on average . Petunia were highly responsive to temperature such that at 12°C plants required 110 days for flowering compared to 58 days at 25°C. Models to predict time to flowering were presented for each of the varieties examined, and these were used to develop sowing date schedules for plants sown on a range of dates and grown at different set point temperatures.

- **Geranium:** Flowering responses of two varieties of seedling geranium cv. Century Rose and Multibloom White were examined. Time to flowering of both varieties were found to be dependent on temperature and light integral. Both varieties were found to be day neutral in terms of their response to photoperiod. The response of geranium to temperature was weaker than other species, since increasing temperature from 15 to 25°C only reduced time to flowering from 120 to 80 days. Sowing date schedules are presented for both varieties of geranium.

Although in any study on plant scheduling it is not possible to examine the full range of varieties used in commercial production, this study has shown that all varieties tested, within a species, had similar responses to environmental variables. No significant variety x environment interactions were found, i.e. early and late varieties tended to be similarly 'early' and 'late' at all environmental combinations. This suggests that the schedules developed here would have wider application for scheduling a much greater range of varieties, since if a particular variety is known to flower a few days later or earlier than those scheduled here, then this difference is likely to be stable throughout the growing the season. The main exception would be salvia, where some varieties are known to flower earlier in short days (Hughes and Cockshull, 1966); those tested here were found to flower earlier in response to long days.

In conclusion this report has presented substantial new information on the effects of environmental variables on time to flowering of 6 of the key bedding plant species. Quantitative models have been developed that can be used to predict time to flowering of a range of varieties of each of the species. These models have been used to develop simple sowing date schedules which growers could use in order to help minimise wastage and to maximise space use efficiency. The schedules reported here were developed using long terms average weather conditions for Reading. The accuracy of any schedule would no doubt be increased if it were tailored for the environmental conditions (outside air temperature, light integral, photoperiod and glasshouse light transmission) on individual nurseries. Towards this end the models developed here are now being incorporated into a computerised decision support program, which will be available to growers through the HDC. This program will use the models to schedule crops, forecast maturity dates of sown crops, determine how temperature can be manipulated to change maturity dates of batches and indicate likely space and product availability in different weeks. It will therefore provide a powerful management tool for bedding plant nurseries. The models are also now being applied in a further study to determine the most profitable growing temperatures for different bedding crops.

1.0 Introduction and Literature Review

Temperature has a profound effect on the time to flowering and final plant quality of a range of bedding plant species. Furthermore, temperature is the one environmental variable over which the majority of growers have a degree of control. However, our quantitative understanding of the effects of temperature on the growth and development of most bedding plant species is still limited, despite the industries economic value. MAFF estimate the farm gate production of bedding plants to be £160M per annum, compared to industry estimates of up to £450M.

A previous HDC funded study at Reading has examined the responses of a number of bedding plant species (primrose, pansy, geranium, impatiens and petunia) to environmental variables, especially temperature (Pearson *et al.,* 1995). This report mainly presented data on the key factors affecting plant quality, and an attempt was made to develop sowing date schedules based on a more limited data set than that gathered here. Key factors affecting the growth and development of plants from each of these species were identified, as follows;

- In *Primrose*, time to flowering was highly dependent on sowing date and temperature, and a further HDC study on primrose (Pearson *et al.,* 1996) has shown that flowering in primrose is a complex function of temperature and photoperiod, such that at temperatures lower than 16°C the plants can flower at any daylength, however, under warmer conditions short days hasten flowering. Quality was also affected by temperature, in that leaf area was reduced at cool temperatures (<10°C).

- In *Pansy*, time to flowering was found to be related to temperature, light integral and photoperiod. Thus, experiments showed that pansy cv Universal Violet was a long day plant with flowering occurring approximately 2-3 weeks earlier in day lengths of $17hd^{-1}$ compared to $8hd^{-1}$. Earliest time to flowering occurred at temperatures of approximately 18°C. Light integral also had a substantial effect on time to flowering, such that sowings at the end of July matured in October, whilst sowings two weeks later (when light level had decreased) matured in March. Optimum plant quality was found at temperatures lower than 14°C.

- In *Impatiens,* time to flowering was mainly related to temperature and plants were day neutral (i.e. day length has no effect on time to flowering). Fastest flowering (53 days) occurred at 24°C, however, plants were of poor quality. Optimum plant quality was achieved at temperatures between 16 to 20°C. Impatiens was very sensitive to cool temperatures and temperatures lower than 15°C greatly prolonged production and led to leaf yellowing and senescence.

- In *Geranium,* time to flowering was mainly affected by temperature and light integral. Shortest time to flowering occurred at mean temperatures of 28°C, however, plants at these temperatures were of very poor quality and suffered from high temperature induced chlorophyll breakdown. The delaying effects of temperature on time to flowering became more pronounced at cooler temperatures, such that at 20°C average time to flowering was 100 days compared to 140 days at 14°C. Final quality was also highly temperature dependent, such that plant fresh weight and height at flowering were greatest at cooler temperatures (14 to 20° C). However, flower number was increased at the cooler temperatures. The reason for the increased weight at flowering under cool temperatures was presumably due to the increased time to reach flowering. Optimum temperatures to produce geraniums were in the order of 18 to 20°C.

- In *Petunia,* time to flowering was again temperature dependent, such that at 18°C plants flowered after 76 days compared to 66 days at 22°C. Longs days (>12hours) also hastened flowering, such that plants grown at $15hd^{-1}$ flowered 14 days earlier than those at $9hd^{-1}$. There was also evidence that morphology changed with photoperiod, such that under short days the plants had a rosette habit, whilst in long days the plants formed few side shoots and flowered on an elongated main axis. Plant quality was optimised at temperatures between 14 to 18°C. At warmer temperatures quality was reduced by excessive stem elongation.

Thus, in the previous HDC program (PC74) a substantial amount of basic work was conducted on a number of the most important bedding species. This has led to the development of tentative sowing date schedules for one variety each of petunia, geranium and pansy. The principal objectives of the work described here was to extend our work to examine the photothermal responses of a number of other key species, namely antirrhinum, marigold and salvia, and to examine the responses of a larger range of varieties. Aspects of further MAFF funded work on geranium, impatiens and marigold are also described here for completeness. For the three new crops (Antirrhinum, Salvia and Marigold) little is also known regarding their responses to environmental variables. For Salvia, Hughes and Cockshull (1966) showed that it has a complex flowering response to environmental variables, for example, some varieties behave as short day plants (flower earlier in response to short day lengths), whilst others are long day plants (flower earlier in response to long day lengths). Marigold has been reported as a short day plant (Hughes and Cockshull, 1966), whilst antirrhinum is well known to be a long day plant (Cockshull, 1985), although a detailed quantitative description (models) of these plants responses to temperature, and interactions with other environmental variables is limited.

Thus, the primary aim of this study was to develop models of the effects of environmental variables on time to flowering of a range of bedding species. To calibrate these models data was gathered from a series of experiments where plants were grown in a range of different photothermal regimes, combining different temperature and photoperiod treatments. Experiments were also conducted with a range of sowing dates to simulate the effects of different light levels, data on time to flowering and basic quality variables were collected. These data were then used to develop models that predict the effects of photothermal environment on time to flowering and plant quality parameters. These models were then applied to develop sowing date schedules.

2.0 Benefits from the Study

The benefits from any study are always difficult to quantify, however, this project will help underpin a number of potential benefits to the industry;

I) Improved scheduling should help to reduce wastage, currently estimated at 10% of all UK production (S. Coutts *pers comme*) equating to net losses at farm gate value of between £16M to £45M per annum (estimated from MAFF and growers figures for the value of the bedding industry).

II) The study will help identify optimal temperatures for plant growth.

III) The study may help identify new marketing opportunities, for example how to extend the season by manipulation of sowing date / growing conditions.

IV) The study will enable growers to forecast the maturity dates of crops after they have been sown. This is an increasingly important requirement of multiple buyers who rely on growers to provide accurate estimates of product availability ahead of sales. Furthermore, if growers can predict gluts or troughs in supply in advance of maturity they can prearrange marketing promotions (to reduce wastage and raise the product profile) or buy in product from elsewhere.

V) This study may help growers optimise space management during the season. Space allocation and management appears to be of critical importance in maximising productivity and minimising wastage, and is highly dependent on the climate inside in the greenhouses. For example, if light levels are low production may be delayed causing a space problem with later preplanned sowings. The models developed here could play a key role in improving space management, since they could be used to identify when space will become available for new crops and also how to optimise its use.

VI) At present there have been few economic studies to determine the most profitable ways in which to grow bedding plants. This is because crop production is highly dynamic and subject to the vagaries of the weather, furthermore the range of environmental conditions in which growers produce their crops is vast. This complexity makes economic optimisation very difficult. This is because it is difficult to attribute one of the largest costs of production -overheads- to any single crop, since until now there has been no way to estimate how long different crops take to grow. Models that determine crop duration can be used to allocate overhead costs accurately. This in turn offers an exciting opportunity to study the factors that maximise the profitability of an enterprise, for example, questions can be addressed that determine whether it is more sensible to increase temperatures to maximise throughput, or decrease them to minimise fuel costs.

3.0 Materials and Methods

3.1 Experiment 1: The Effects of Temperature and Sowing Date on Time to Flowering.

Plants from each of the species and varieties used were sown on the dates shown in Table 1.

Table 1. The Species, Varieties and Sowing Dates used in Experiment 1.

Species	**Variety**	**Sowing Dates**	**Germ[t] Temp**
Antirrhinum	Tahiti	22/2/94, 20/4/94, 18/4/95	17.5
	Coronette Yellow	22/2/94, 20/4/94, 18/4/95	
Geranium	Century Rose	22/2/94,20/4/94,27/6/94, 8/8/94	17.5
	Multibloom White	22/2/94,20/4/94,27/6/94, 8/8/94	
Impatiens	Accent Red Star	2/3/94,27/4/94,27/6/94,12/9/94 18/1/95, 20/4/95	20
	Super Eflin Blue Pearl	2/3/94,27/4/94,27/6/94,12/9/94 18/1/95, 20/4/95	
Marigold	Aurora Fire	2/5/94, 27/6/94, 12/9/94	20
	Yellow Boy	2/5/94, 27/6/94, 12/9/94	
Salvia	Flamex	22/2/94, 20/4/94, 18/4/95	20
	Sizzler Red	22/2/94, 20/4/94, 18/4/95	
Petunia	Express Blush Pink	22/2/94, 20/4/94, 18/4/95	20
	Purple Flash	20/4/94, 18/4/95	
	Frenzy Light Blue	22/2/94, 20/4/94, 18/4/95	

Plants were grown according to the protocol described by Pearson *et al.*, (1995). Seed were sown in a standard seed tray containing SHL seed compost. Seed trays were then placed in a growth cabinet set at 17 - 22°C, depending on species (see Table 1 for details) where seed were allowed to germinate and grow on for 21 days from sowing. Subsequently, seedlings were pricked out into P84 plug trays (containing the same compost) and a tray of each variety were placed in one of six temperature controlled greenhouse compartments set at minimum temperatures of 6, 10, 14, 18, 22 and 26°C, with ventilation at 4°C higher than the set point. When the plants could be drawn from the plugs, 20 of each variety were selected randomly and potted on into 9cm pots containing Levingtons Potting Compost. Pots were spaced at a density of 40 plants per m^2. They were watered as necessary and fed twice weekly with a nutrient solution containing Sangral 1:1:1 fertiliser (20N: $20P_2O_5$: $20K_2O$) diluted to a conductivity of 1500µS. Time to flowering was recorded. At flowering the plants were removed and six randomly sampled plants were dissected to assess height, leaf number and branch number.

Actual temperatures were recorded with a Datataker data logger (Series 500) using PT100 temperature sensors. Daily light integral (250 to 3000nm) was measured outside the greenhouse using a Kipp-Zonen pyranometer (solarimeter). A greenhouse light transmission of 70% was assumed in all the models (this was estimated from measurements in the greenhouse compartments).

3.2 Experiment 2: Interactions between Temperature and Photoperiod

A second series of experiments were conducted to assess the effects of photoperiod and temperature on time to flowering of the varieties examined. Plants were grown in a combination of four photoperiods combined factorially with two night temperatures. Plants were grown in a specialised photoperiod controlled glasshouse facility. This contained a number of photoperiod/temperature controlled garages. Plants remained inside the greenhouse compartments from 08:00h to 16:00h each day. At 16:00h each day, plants were wheeled into the light tight photoperiod chambers where the photoperiods were extended for the desired period at a photon flux density of $5\mu mol m^{-2} s^{-1}$ provided by a 60:40 mix of tungsten and fluorescent lamps (determined on the basis of nominal wattage). The photoperiod treatments imposed were 9, 11, 14 and $17hd^{-1}$. The two night temperatures, imposed for 16 hours whilst the plants remained inside the photoperiod garages, were 10 and 20°C. Daytime temperature, whilst the plants remained inside the glasshouse compartment, was set at 18°C, with ventilation 4°C higher.

Ten replicate plants for each variety were placed in each treatment. Plants were grown using the protocol described above

Plants from each of the species were sown on the dates shown in table 2.

Table 2. Sowing dates used for experiment 2.

Species	Variety	Sowing Dates
Antirrhinum	Tahiti	3/3/94, 20/4/94
	Coronette Yellow	3/3/94, 20/4/94
Geranium	Century Rose	17/6/94, 17/1/95, 20/4/95, 18/1/96
	Multibloom White	17/6/94, 17/1/95, 20/4/95, 18/1/96
Impatiens	Red Star	17/6/94, 17/1/95, 20/4/95, 18/1/96
	Super Eflin Blue Pearl	17/6/94, 17/1/95, 20/4/95, 18/1/96
Marigold	Aurora Orange	17/6/94, 17/1/95, 20/4/95, 18/1/96
	Yellow Boy	17/6/94, 17/1/95, 20/4/95, 18/1/96
Salvia	Flamex	3/3/94, 20/4/94
	Sizzler Red	3/3/94, 20/4/94
Petunia	Express Blush Pink	3/3/94, 20/4/94
	Purple Flash	20/4/94
	Light Blue	3/3/94, 20/4/94

3.3 Experiment 3: MAFF Funded Experiments Used For Model Calibration

A further series of experiments were conducted in a related study funded by MAFF, and data gathered from these experiments were also used to calibrate the models. These experiments were conducted to quantify potential interactions between temperature, photoperiod and light integral. Basically plants were grown in the same photoperiod controlled facility as described above, but with a further factorial combination of four light treatments were imposed (using 0, 25, 35 and 60% shading) as well as the four photoperiod and two temperature treatments described above (see section 3.1). Only two varieties of impatiens (Accent Red Star and Super Elfin Blue Pearl), two varieties of marigold (Aurora Fire and Yellow Boy), and two varieties of geranium (Century Rose and Multibloom White) were used. The experiment was repeated on four different occasions. Plants were grown as above, but with six replicate plants per variety.

4.0 RESULTS

4.1 ANTIRRHINUM

4.1.1 EFFECTS OF TEMPERATURE ON TIME TO FLOWERING

Figure 1 demonstrates the effects of temperature on time to flowering of both cv. of antirrhinum grown in experiment 1 from three different sowing dates.

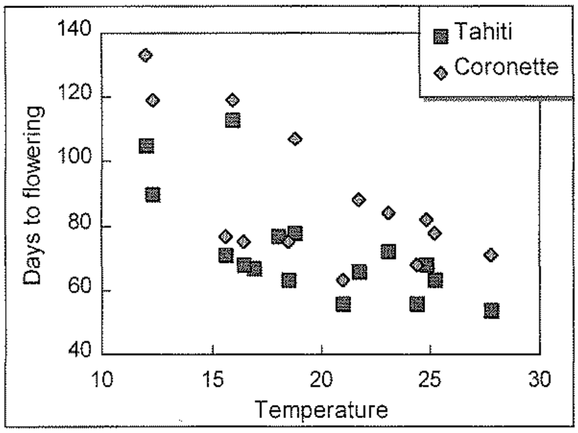


Figure 1. The effects of temperature on the time to flowering of Antirrhinum.

This shows that temperature had a considerable effect on time to flowering. Increasing temperature decreased time to flowering for both cultivars, such that at 12°C cv. Coronette Yellow required approximately 130 days to flower compared to 70 days at 25°C. However, the data show a degree of scatter which suggests that environmental variables other than temperature were influencing time to flowering. This is also reflected by data on leaf number below the flower for different sowing dates and temperatures (Figure 2). For cv. Coronette, earlier sowings, when days were short, led to an increased leaf number below the flower at all temperatures (leaf numbers from the January sowing were almost double those of the April sowing). These differences in leaf number with sowing date suggest that time to flowering initiation was delayed with earlier sowings, probably reflecting effects of either changed photoperiod or light integral. Similar responses were also found for cv. Tahiti.

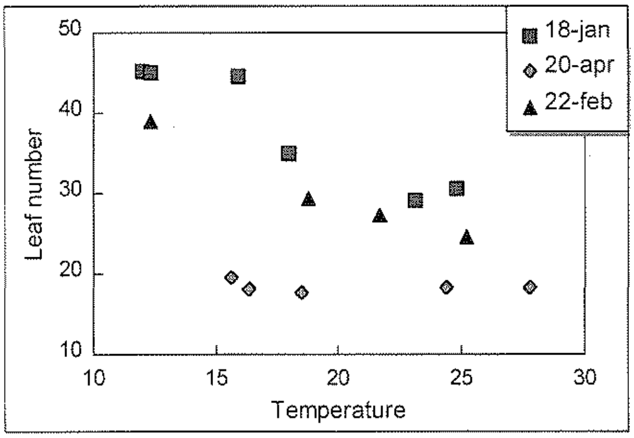


Figure 2. The effects of sowing date and temperature on the final leaf number below the flower of Antirrhinum cv. Coronette Yellow.

Other effects of temperature on plant quality are shown in Plate 1. This plate suggests that increased temperature led to an increased final plant height. However, due to the increased leaf number and time to flowering lower temperatures generally led to the tallest plants *at flowering*, see Figure 3. Similar responses were found for cv. Tahiti.

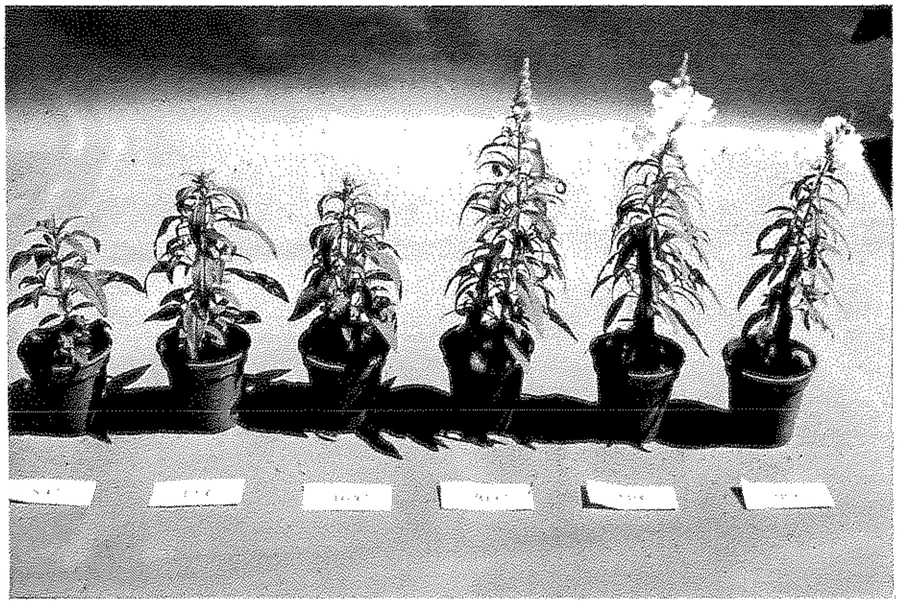


Plate 2. The effects of temperature on the growth and flowering of Antirrhinum cv. Coronette Yellow.

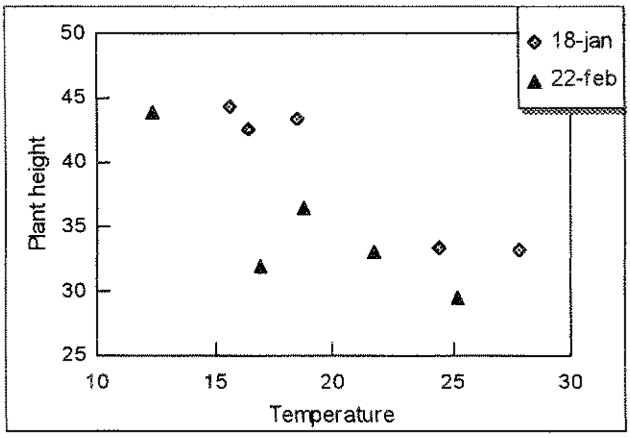


Figure 3. The effects of temperature and sowing date on the plant height at flowering of Antirrhinum cv. Coronette Yellow.

4.1.2 Effects of Photoperiod on Time to Flowering

Figure 4 shows the effects of temperature and photoperiod on time to flowering of antirrhinum determined from experiment 2 for cv. Tahiti. A similar response was shown for cv. Coronette Yellow.

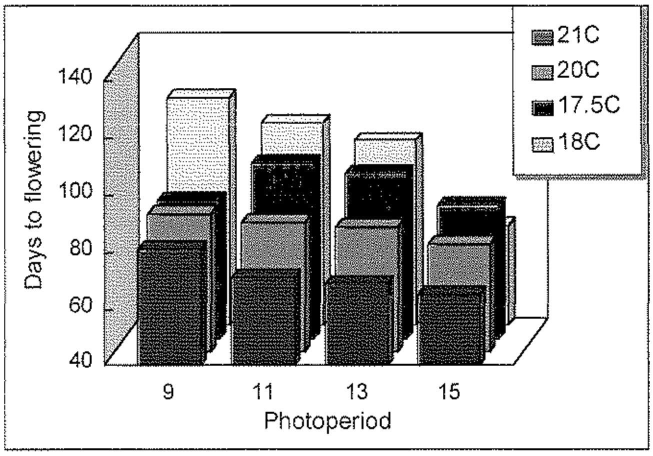


Figure 4. The effects of temperature and photoperiod on time to flowering of antirrhinum cv. Tahiti.

This confirmed that decreasing temperature led to a significant ($P<0.05$) delay in time to flowering. Furthermore, the analysis confirmed that antirrhinum are a weak long day plant ($P<0.01$), such that for cv. Tahiti plants grown at $15hd^{-1}$ photoperiods flowered 18 days earlier than those at $9hd^{-1}$. In terms of final plant quality, increased photoperiod had little overall effect (see Plate 2), however, leaf number below the flower was increased with short days (data not shown). This response to photoperiod therefore probably explains the change in leaf number with sowing date shown above, see figure2.

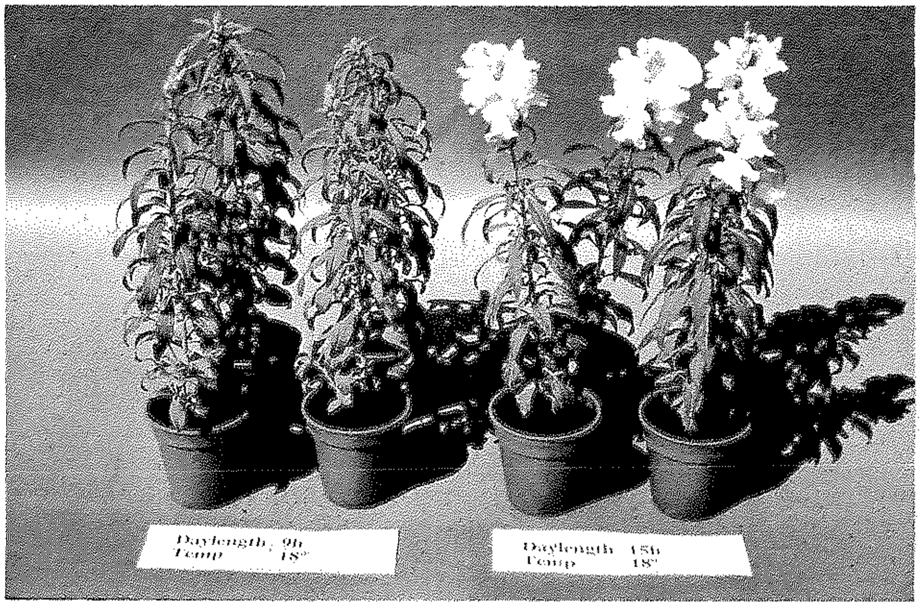


Plate 2. The effects of photoperiod on flowering of Antirrhinum cv. Coronette Yellow.

4.1.3 SCHEDULING ANTIRRHINUMS

In order to develop a sowing date schedules, all the data was combined into a single 'regression' analysis. This type of analysis provides a mathematical equation relating the effects of environmental variables on time to flowering. It also indicates the level of significance of different environmental variables (similar to that provided by a conventional analysis of variance) and the proportion of the total variance explained by the analysis. For antirrhinum this type of analysis confirmed that the main factors affecting time to flowering were photoperiod and temperature. Effects of different light integrals were also analysed, by combining all the data from the different experiments into the analysis together with their respective light integrals, but in this instance no significant effect of light was found. The final fitted relationships (including only parameters with a probability of significance greater than 0.05) for cv Tahiti was;

$$1 / f = -0.00239 + 0.000456T + 0.00056P \qquad (r^2 = 0.75, 30 d.f.)$$

where f is the days to flowering and T is temperature and P is photoperiod. The r^2 was 0.75 which suggests that 75% of the variation associated with the data was explained by the regression equation. This equation, or any of the others presented here can be used in a simple manner to determine how long a crop will take for maturity, for example if the mean diurnal temperature is 18°C and the mean daylength is 12 hours then the equation would predict that the crop will require;

$f = 1 / (-0.00239 + 0.000456 * \mathit{18} + 0.00056 * \mathit{12})$

$f = 79.8$ days

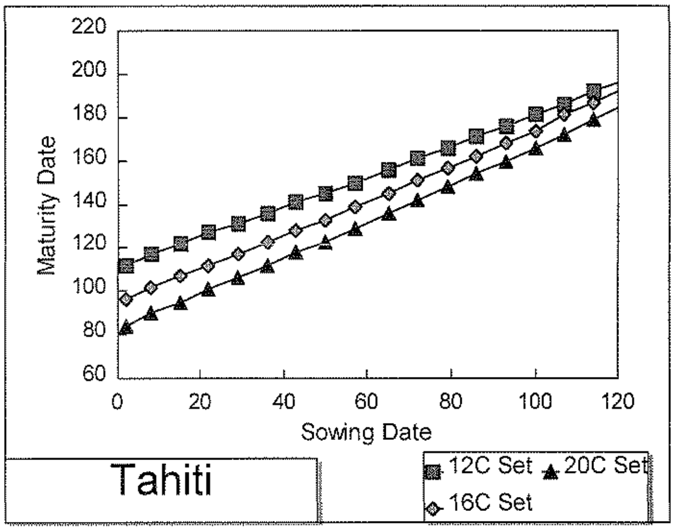
For cv Coronette Yellow the relationship to predict time to flowering developed from 26 crops was as follows (see appendix for diagrammatic representation);

$f = 1/ (-0.00291 + 0.000319T + 0.000592P)$ ($r^2 = 0.71$, 24d.f..)

The relationship for Tahiti and Coronette Yellow should give prediction accuracies to within ± 9.3 and 8.7 day, respectively. The above worked example demonstrates how the model can be used to predict time to flowering of a crop grown in constant environmental conditions. However, under commercial glasshouse conditions temperatures and photoperiod will vary. Consequently, a computer program was written to consider this in terms of schedule development. This program predicts time to flowering using the models in conjunction with long term mean weather files in order to determine likely greenhouse temperatures, photoperiods (and light integrals where required).

Figure 5a and b shows the sowing date schedules developed for both Tahiti and Coronette Yellow. To simulate a plug and seedling production stage, the schedules assumed that the plants were raised at 18°C for the first 25% of their production period,. Thereafter, the plants were assumed to be grown at one of three different set point temperatures (12, 16 and 20°C). It was also assumed that as outside temperatures increased through the season that the set points could not be maintained. When this occurred the glasshouse temperatures were assumed to be 4°C higher than the long term average outside temperature (data from Reading). Daily photoperiods were calculated from astronomical equations and based on Reading's latitude. Photoperiod will change slightly with more Northerly or Southern locations. Long terms temperatures, photoperiods and light integrals used in the schedule development are shown in Appendix 1.

5a



5b

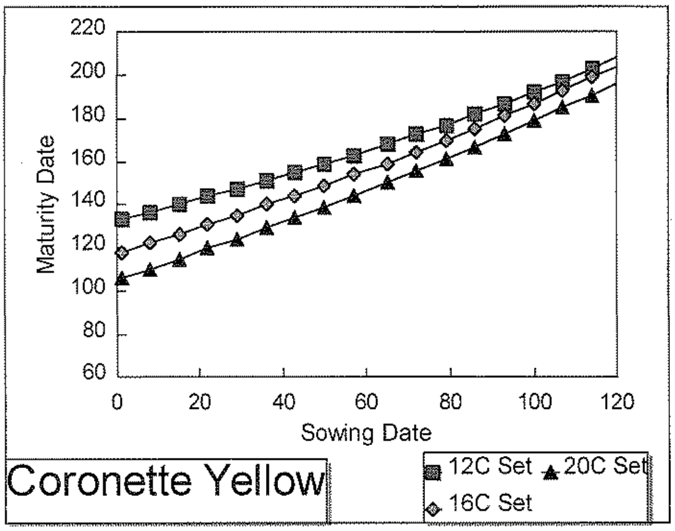


Figure 5a and 5b. Sowing date schedules for antirrhinum cv's Coronette Yellow and Tahiti for plants produced at three different set point temperatures.

These schedule show that Tahiti matures about 10 to 20 days earlier than Coronette Yellow.

Different set point temperatures have greatest effect on time to crop maturity during the early part of the season, when outside air temperatures are cold; since as the season progresses and outside temperatures increase it will become increasingly difficult to maintain the glasshouse at the cooler set point temperatures. The schedules also show that time to crop maturity decreases with later sowings, for example for cv Coronette Yellow grown at 16°C sowings on 1 January will require 136 days to mature compared to 85 (205 - 120) days for a sowing on 30 April (day number 120). This is because photoperiod increases with time through the season (and antirrhinum flower earlier in long days) and outside temperatures will also increase with time.

4.2 Salvia

4.2.1 Effects of Temperature on Time to Flowering of Salvia

Two varieties of salvia were examined during the project; Sizzler Red and Flamex. Increased temperatures led to substantial reductions in time to final flowering (see Figure 6). For example for cv. Sizzler Red mean diurnal temperatures of 12°C led to final flowering after approximately 100 days compared to 58 days at 25°C. Similar reductions were noted for cv. Flamex which on average flowered 6 days later at all temperatures than Sizzler Red. Temperature had little effect on the final leaf number below the flower, however, leaf number was affected by sowing date ($P<0.001$), such that the January, February and April sowings had leaf numbers averaged 13, 9 and 12, respectively, for all temperature treatments.

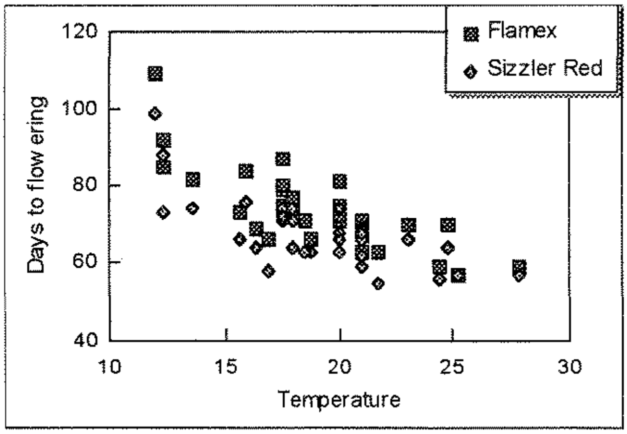


Figure 6. The effects of temperature on the time to flowering on Salvia cv's Flamex and Sizzler Red.

Plate 3 shows the effects of temperature on the final quality of Salvia. It was observed that higher temperatures led to a linear increase in plant height at flowering and poorer final quality (Figure 7). There were considerable effects of sowing date on final plant height, with the January sown plants being significantly taller than those sown in February. This difference probably reflects differences in final leaf number below the flower reported above.

Plate 3. The effects of temperature on the flowering of Salvia cv. Sizzler Red.

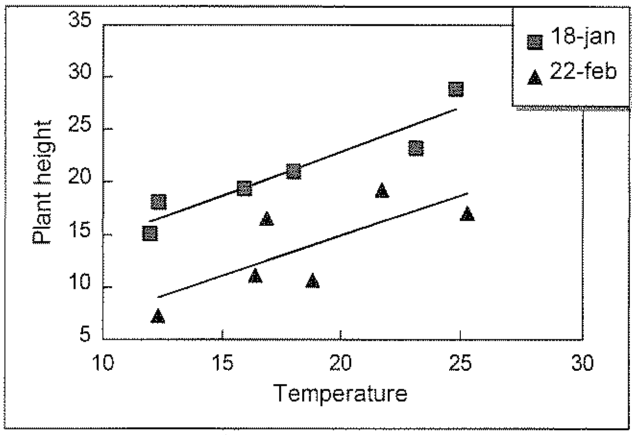


Figure 6. The effects of sowing date and temperature on the final plant height of salvia cv. Sizzler Red at flowering.

4.2.2. Effects of Photoperiod on Flowering of Salvia.

Figure 7 shows the effects of both temperature and photoperiod on the time to flowering of salvia cv. Flamex, similar responses were noted for cv. Sizzler Red.

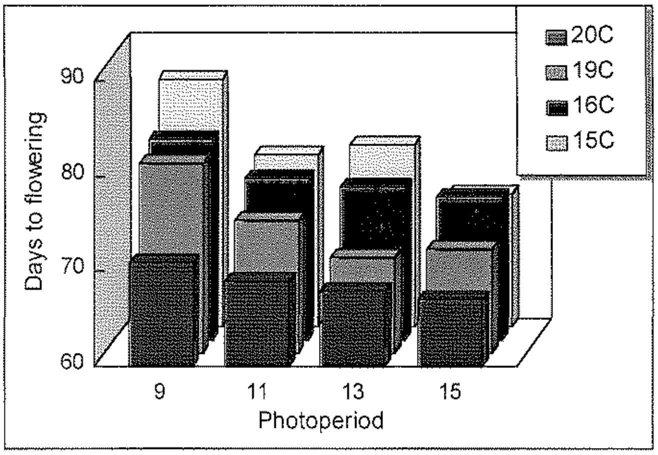


Figure 7. The effects of photoperiod and temperature on the time to flowering of salvia cv. Flamex.

This shows that at short photoperiods time to flowering was delayed ($P<0.05$). However, the response was small, on average long photoperiods only hastened flowering by 10 days. The data also confirmed that as temperatures increased time to flowering was hastened. Plate 4 shows the effects of photoperiod on the final plant quality of cv. Sizzler Red. This shows that different photoperiods had little effect on final plant quality.

4.2.3. SCHEDULING SALVIA

Equations were developed to relate the effects of environmental variables on the time to flowering of Salvia (similar to those described for Antirrhinums in section 4.1.3), using the combined data sets for both experiments. The combination of the data sets also allows us to test for effects of different light integrals and for cv. Flamex high light integrals were shown to significantly reduce time to flowering. This is shown by the final fitted equation developed from 30 different crops, thus;

$$1/f = 0.004 + 0.00035T + 0.000184P + 0.000104M \qquad (r^2 = 0.84, 30\text{ d.f.})$$

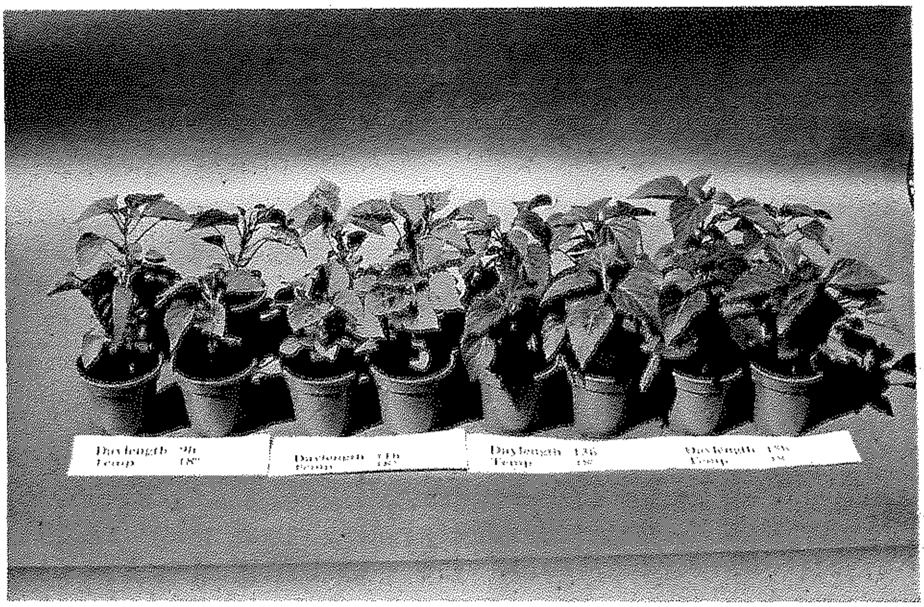


Plate 4. The effects of different photoperiods on the flowering of Salvia cv. Sizzler Red.

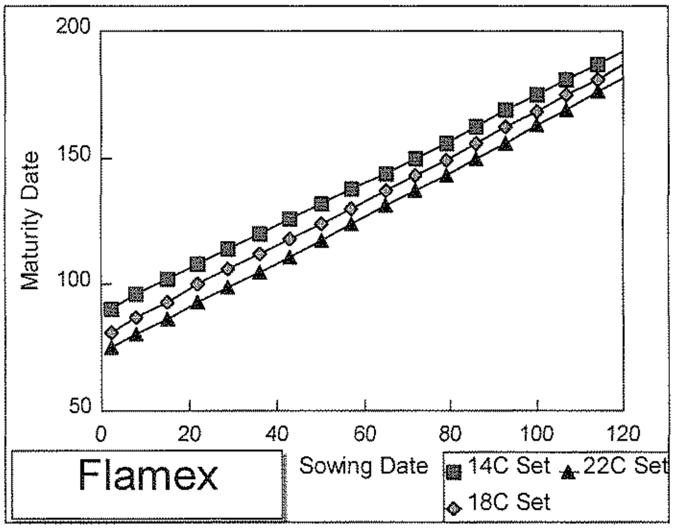
where M is the daily light integral ($MJm^{-2}d^{-1}$; total solar radiation 350-2500nm transmitted through the glass). This equations states that time to flowering is reduced significantly by increasing temperature, photoperiod and light integral. To illustrate the magnitude of the light response, as daily light integral increases from $2MJm^{-2}d^{-1}$ (January day) to $10MJm^{-2}d^{-1}$ (May day) time to flowering is predicted to decrease from 79 to 74 days if the mean temperatures and photoperiods are 18°C and $12hd^{-1}$, respectively. Thus, the response is small relative to the effects of temperature and photoperiod.

A similar analysis was performed for cv. Sizzler Red although on this occasion the effects of light integral were not found to be significant, and the relationship relating time to flowering from 33 crops to temperature and photoperiod was found to be (see appendix for diagrammatic representation);

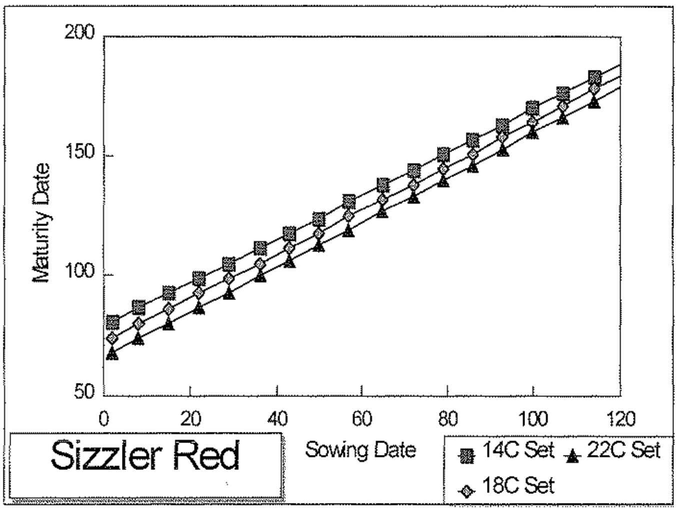
$$1/f = 0.00545 + 0.000322T + 0.000288P \qquad (r^2 = 0.72, 31d.f.).$$

The above relationships were used to develop sowing date schedules, according to the protocols described for antirrhinum above (see figures 8a and 8b).

8a



8b



Figures 8a and 8b. Sowing date schedules for salvia cv's Flamex and Sizzler Red.

These schedules show that salvia crops grown at the cooler temperature regime will mature consistently later than those grown at 22°C more or less regardless of sowing date.

4.3 Marigold

The data reported here was gathered as part of a recent MAFF funded program on scheduling bedding plants conducted at Reading.

4.3.1. Effects of temperature on time to flowering

Figure 9 shows the effects of temperature on time to flowering of Marigold cv's Yellow Boy and Aurora, data shown are combined from the May and September sowing dates in experiment 1 (data from other sowings showed similar responses).

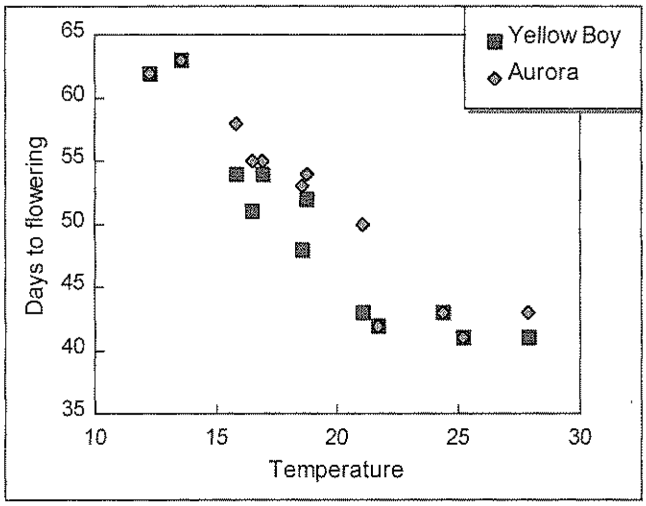


Figure 9. The effects of temperature on the time to flowering of marigold cv's Yellow Boy and Aurora.

This shows that in marigold time to flowering was highly responsive to temperature, such that for cv. Aurora flowering occurred after 63 days at 12°C compared to 41 days at 25°C. On average Yellow Boy flowered 2 days earlier than Aurora. Leaf number below the flower was hardly affected by temperature or sowing date; averaged across all temperatures the January, February and April sowings had mean leaf numbers of 7, 7.5 and 8, respectively. Plant quality was also affected by temperature and sowing date. Figure 10 shows that plant height of cv. Yellow Boy increased linearly with temperature.

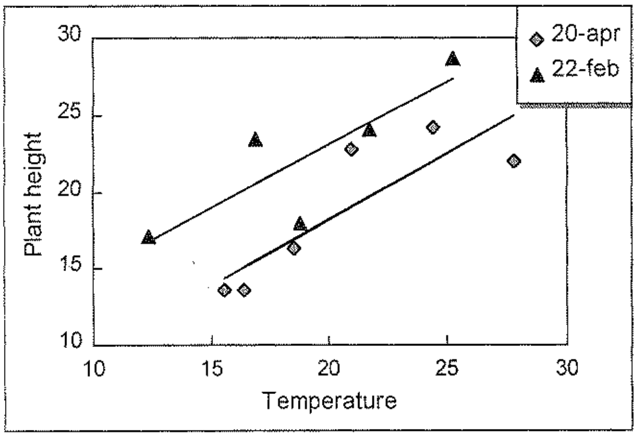


Figure 10. The effects of sowing date and temperature on the final plant height of marigold cv. Yellow Boy at flowering.

Final branch number below the flower was not significantly affected by sowing date with on average 6.3 branches being formed per plant. Temperature had a small but significant (P>0.05) effect on final branch number, for example for the February sowing at 12.3°C plants had on average 7.8 branches compared to 6.1 when temperatures averaged 25°C.

4.3.2. The effects of photoperiod and light integral on time to flowering

For marigold a large experiment was conducted in order to investigate the combined effects of temperature, photoperiod and light integral on time to flowering (experiment 3). In this experiment plants were grown at a range of different shade levels combined with four different photoperiods and two night temperatures. This experiment showed that time to flowering of marigold was highly dependent on the light integral (see figure 11).

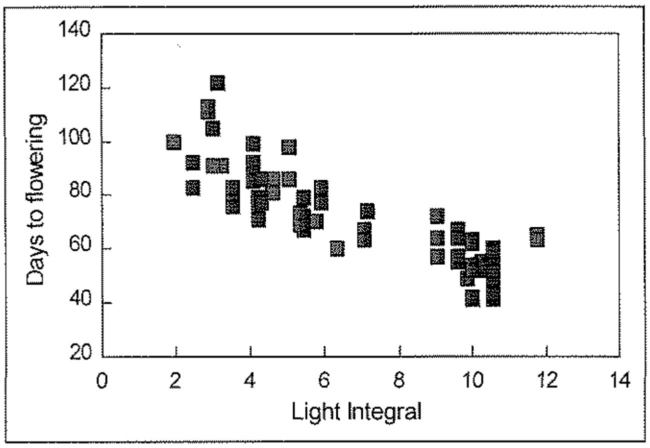


Figure 11. The effects of light integral ($MJm^{-2}d^{-1}$, total transmitted solar) on time to flowering of marigold cv. Yellow Boy.

Thus, at light integrals equivalent to January (2 $MJm^{-2}d^{-1}$), 100 days are required for flowering compared to 50 days at light integrals which equate to a May day (10$MJm^{-2}d^{-1}$). Similar responses were found for cv. Aurora.

No significant effects of photoperiod were detected in terms of time to flowering, although there was a suggestion (not significant) with cv. Aurora that short days advanced time to flowering.The lack of a photoperiod response was surprising, since in the literature this plant has been previously reported as a weak short day plant (Hughes and Cockshull, 1966). However, it is possible that a short day response with these cultivars is only found at high temperatures, since for the June sowing of experiment 1 (examining temperature responses of plants under glasshouse conditions), it was noted that plants did not flower when temperatures were greater than 22°C, see Plate 5. An explanation of this response would be that at very high temperatures Marigold require short days to flower (this is a typical response of many short day species), since days were on average longer for this sowing than any other.

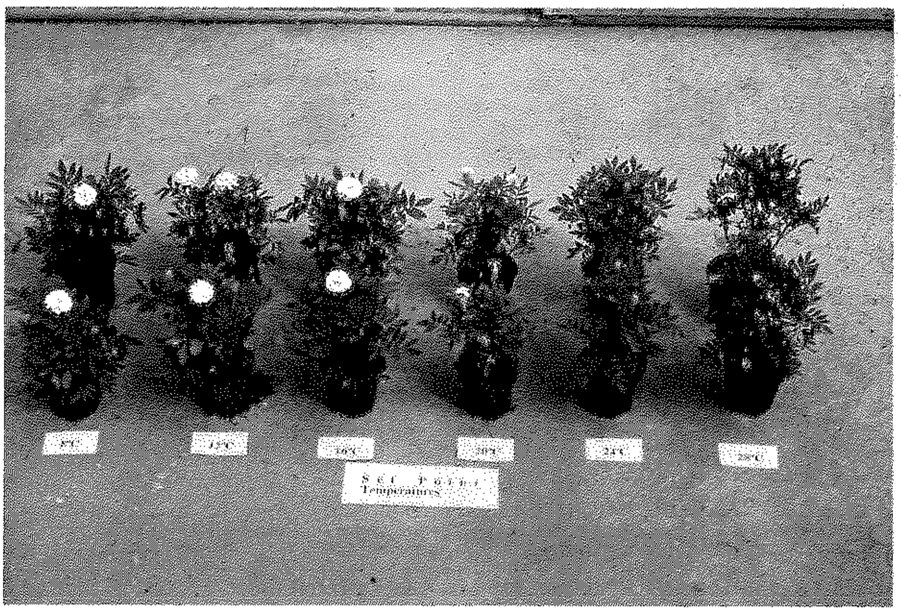


Plate 5. The effects of temperature on flowering of Marigold sown during June.

4.3.3. Scheduling Marigolds

Data from all the experiments were combined into a single analysis to develop a relationship to predict time to flowering. For cv. Yellow Boy the following relationship was determined from 75 separate crops, where (see appendix for diagrammatic representation);

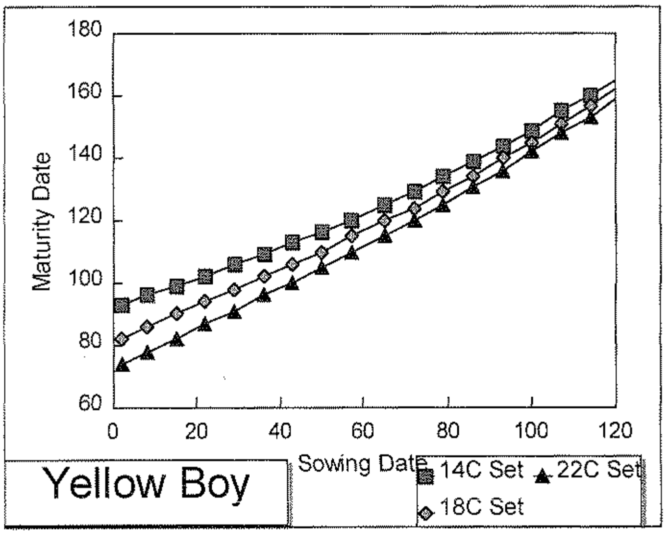
$$1/f = -0.00128 + 0.000508T + 0.001009M \qquad (r^2 = 0.81, 72d.f.)$$

For cv. Aurora data from 81 crops were used in the analysis which provided the final fitted equation as;

$$1/f = 0.000089 + 0.000647T + 0.000582M \qquad (r^2 = 0.79, 78d.f.)$$

Both these relationships gave a good fit to the data accounting for 81 and 79% of the variance in time to flowering for Yellow Boy and Aurora, respectively. They indicate that time to flowering is significantly reduced as either temperature or light integrals increase. These relationships were used to develop sowing date schedule for both Marigold varieties, using the protocol described in section 4.1.3 (see Figure 12).

12a



12b

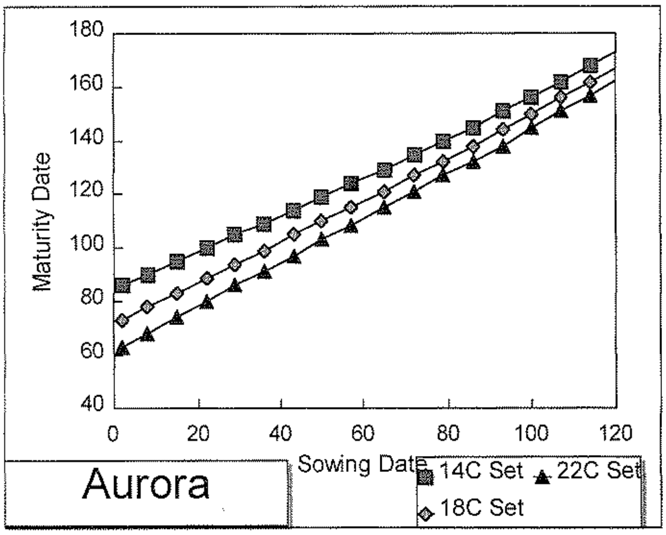


Figure 12. Sowing date schedules for marigold cv. Yellow Boy and Aurora Fire.

These schedules show that at early sowing dates there is a considerable delay in time to maturity at different set point temperatures, however, these become progressively smaller with later sowings, presumably because outside air temperatures and light integrals increase.

4.4 Impatiens

Preliminary observations of the factors affecting flowering and quality of impatiens are presented in the previous report (Pearson *et al.,* 1995). Here further data are presented on the flowering responses as well as sowing date schedules. Data gathered during experimentation funded by MAFF are also presented.

4.4.1 The effects of temperature on the time to flowering of impatiens

Two varieties were examined Red Star and Blue Pearl. Figure 13 shows the effects of temperature on time to flowering of 38 and 22 crops of Blue Pearl and Red Star, respectively, grown in glasshouse compartments at natural light integrals and photoperiods. Data collected from Blue Pearl during the first HDC project (Pearson *et al.*, 1995) are also included on figure 13.

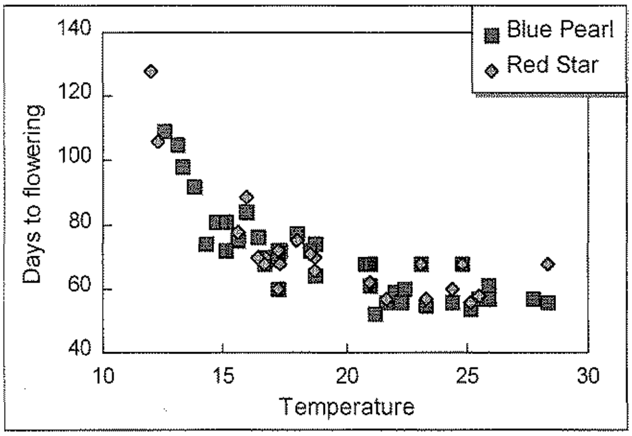


Figure 13. The effects of temperature on the time to flowering of impatiens cv. Blue Pearl and Red Star.

This shows that time to flowering decreased curvilinearly as mean temperature increased, such that at a mean temperature of 12°C 120 days were required to flowering, compared to 55 days at 20°C. Above 20°C, further increases in temperature had no additional effect on time to flowering. There were no discernable differences in time to flowering between the two varieties at any temperature. A detailed description of factors affecting plant quality was presented in the previous report.

4.4.2 EFFECTS OF PHOTOPERIOD AND LIGHT INTEGRAL ON TIME TO FLOWERING OF IMPATIENS.

An extensive experiment was conducted to assess the effects of four photoperiods, three shade levels and two night temperatures on time to flowering of Blue Pearl and Red Star (see section 3.3). This experiment, repeated on four different occasions, showed that photoperiod had no significant effect on the time to flowering of both varieties. Thus, impatiens can be considered as day neutral plants. However, time to flowering was found to be dependent on light integral (see Figure 14), as well as temperature.

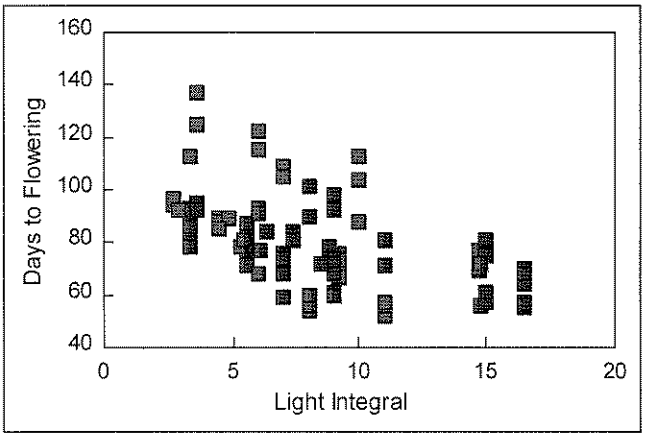


Figure 14. The effects of light integral ($MJm^{-2}d^{-1}$, total solar radiation) on time to flowering of impatiens cv. Blue Pearl.

Figure 14 shows the combined data from 100 different crops of Blue Pearl. This shows that as light integral increases time to flowering decreases. The effects were substantial since as light integral increases from 3 to $15MJm^{-2}d^{-1}$ (February compared to a June day) time to flowering is halved from 120 to 60 days. However, the relationship with light integral shows considerable scatter, reflecting the fact that the data encompasses plants grown at a range of different temperatures as well as light integrals. Similar responses were also shown for cv. Red Star.

4.4.3 Scheduling Impatiens

Data from all the experiments were combined into a single analysis to predict the effects of light integral and temperature on the time to flowering. For cv. Blue Pearl the following relationship was developed to predict flowering (see appendix for diagrammatic representation);

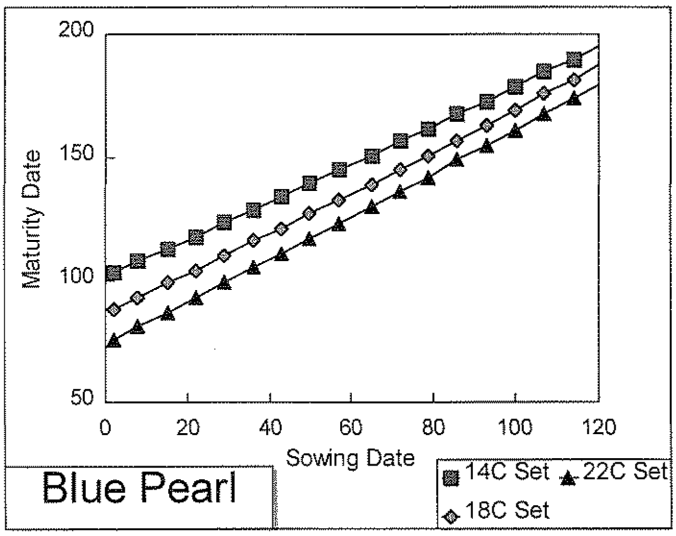
$1/f = 0.001192 + 0.000513T + 0.000265M$ ($R^2 = 0.70$, 97d.f.)

For cv Red Star the relationship was;

$1/f = 0.001245 + 0.000486T + 0.000255M$ ($R^2 = 0.68$, 79d.f.)

These indicate that increasing light integral and temperature reduce time to flowering. Both the relationships were used to develop sowing date schedules for impatiens using the protocol described in section 4.1.3, and are shown in Figures 15a and b.

15a



15b

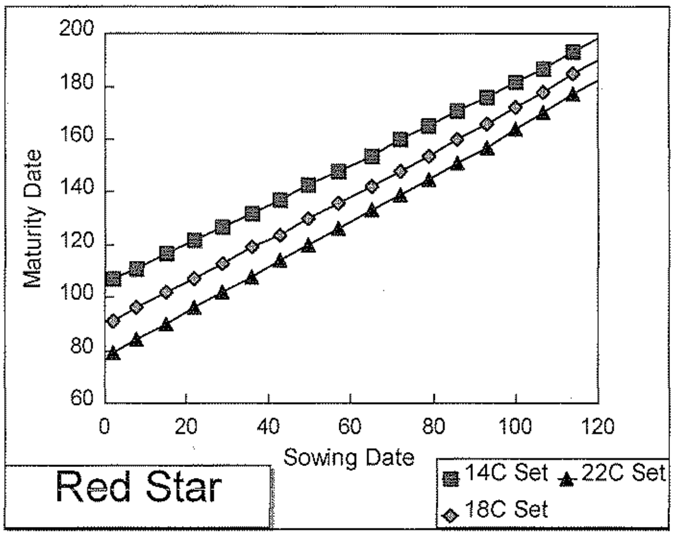


Figure 15 a and b. Sowing date schedules for impatiens cv. Blue Pearl and Red Star.

These schedules show that crops grown at 14°C would be considerably delayed (by between 27 to 15 days) compared to those at 22°C. 14°C represents the cold temperature limit for impatiens production, below this temperature growth is greatly retarded, leaves drop and quality is reduced (Pearson *et al.,* 1995).

4.5 Petunia

Factors affecting flowering and quality of petunia cv. Express Blush Pink have been previously reported (Pearson *et al.*, 1995). Here further data are reported on the flowering responses of Express Blue Pink and two other cultivars; Purple Flash and Light Blue.

4.5.1 Effects of Temperature on flowering of petunia

Figure 16 shows the effects of temperature on the time to flowering of 33, 16 and 10 crops of Express Blush Pink, Light Blue and Purple Flash, respectively, grown in glasshouses under natural light integrals and photoperiods (experiment 1). Also included on figure 16 are data for Blush Pink presented in the previous report.

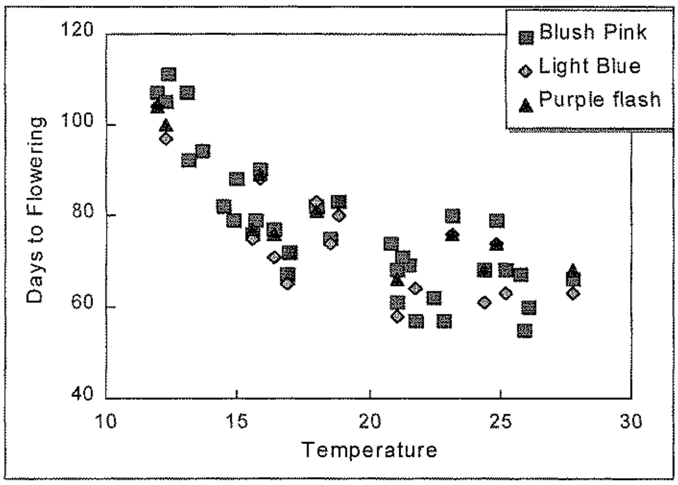


Figure 16. The effects of temperature on the time to flowering of petunia.

Figure 16 shows that as temperature increases time to flowering decreases. The sensitivity to temperature was considerable, such that at 12°C plants required 110 days to flower compared to 58 days at 25°C. Figure 16 shows a degree of scatter, which can be partially attributed to the fact that the plants were grown at different photoperiods, which have previously been reported to affect time to flowering (see below). Temperature responses of different varieties were similar. In terms of average times to flowering between varieties cv. Light Blue flowered 3 days earlier than Purple Flash which flowered 1 day earlier than Blush Pink. As described in the previous report, it was observed for all varieties that quality deteriorated at high temperatures with increased plant height and lower branching (see Pearson *et al.,* 1995).

4.5.2 Effects of Temperature and Photoperiod on Time to Flowering

In the second experiment plants of all three varieties were grown at one of two different temperatures and photoperiods. Figure 17 shows that time to flowering for cv. Light Blue was reduced significantly ($P<0.01$) as photoperiod increased. Plants required, on average, 103 days to flower at a photoperiod of $9hd^{-1}$ compared to 81 days at $15hd^{-1}$. As previously reported (Pearson *et al.,* 1995; Adams *et al.*, 1997) photoperiod has a dramatic effect on plant quality. Under long days plants flower on a single main stem with few branches, whereas under short days the plants form a rosette and flower from a branch. This is illustrated in Plate 6 which shows plants of cv. Blush Pink sown in January and produced in natural photoperiods when days are short. Plate 7 shows the same variety of petunia but sown during April.

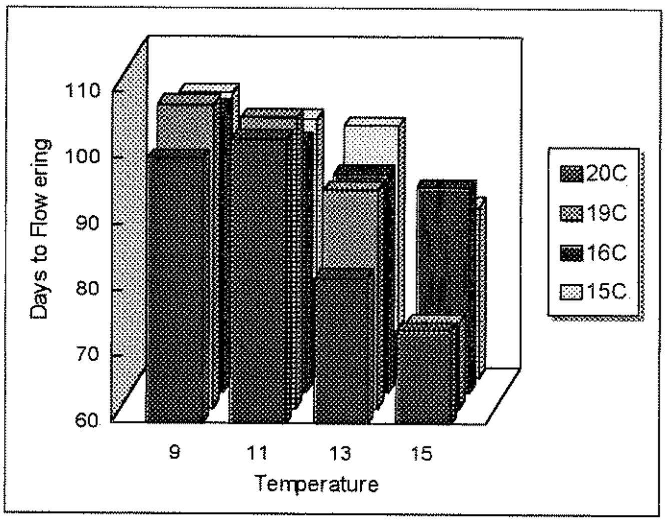


Figure 17. The effects of photoperiod and temperature on the time to flowering of Petunia cv. Light Blue.

Plate 6. Petunia cv. Express Blush Pink sown on 18 January 1995 and grown at one of six different temperatures.

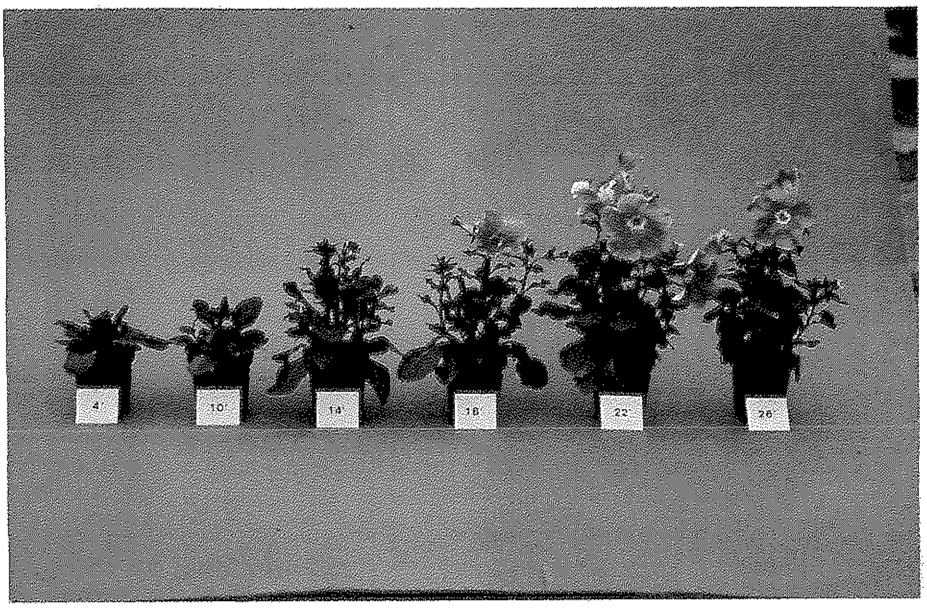


Plate 7. Petunia cv. Express Blush Pink sown during April 1993 and grown at one of six different temperatures (reproduced from Pearson *et al.*, 1995).

4.5.3. SCHEDULING PETUNIA

Data from the experiments were combined to produce relationships to predict maturity of Petunia. In this analysis effects of different light integrals were tested, but no significant response was found. This may because all the crops were grown at relatively high light integrals 5 to 15 $MJm^{-2}d^{-1}$, but these light integrals cover the majority of the range likely to be experienced in commercial production.

For cv. Express Blush Pink, the following relationship was developed to predict flowering (see appendix for diagrammatic representation);

$1/f = -0.00202 + 0.000383T + 0.000573P$ ($r^2 = 0.73$, 47d.f.).

For cv. Light Blue, the relationship was as follows;

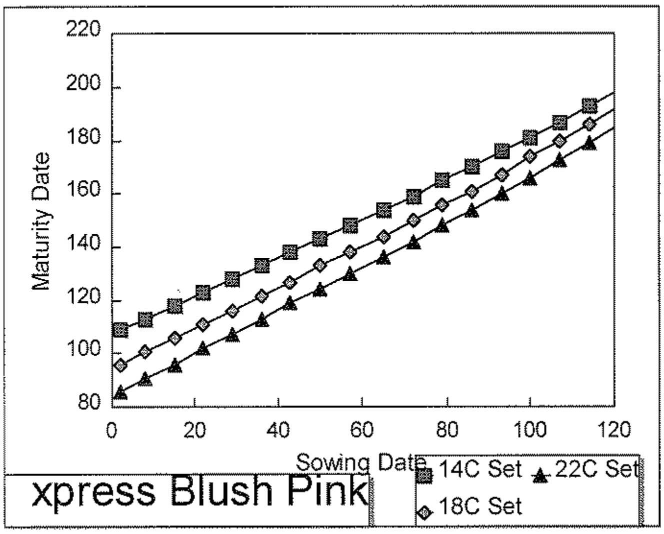
$1/f = -0.00199 + 0.000332T + 0.000634P$ ($r^2 = 0.68$, 29d.f.)

and for Purple Flash;

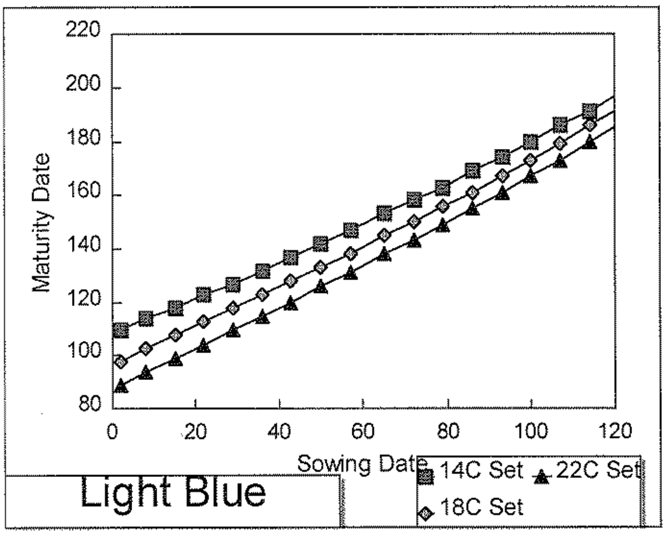
$1/f = 0.001908 + 0.000246T + 0.00043P$ ($r^2 = 0.78$, 16d.f.).

These relationships gave a good description of the factors affecting flowering in petunia, accounting for 68 to 78% of the total variation, and indicate that increasing temperature and day length reduce time to flowering. Figure 18a,b and c show sowing date schedules for each of the cultivars.

18a



18b



18c

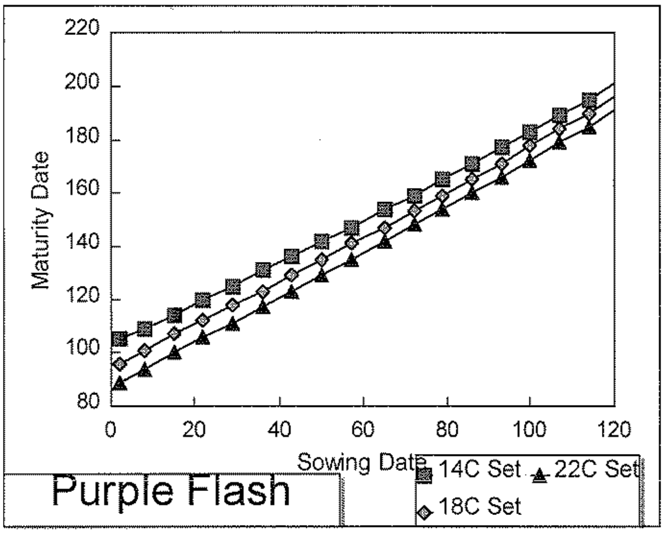


Figure 18. Sowing date schedules for petunia Express Blush Pink, Light Blue and Purple Flash.

The three varieties examined have shown considerable similarity in their responses to environmental variables. This suggests that the schedules developed here may have a wider application to a much greater range of cultivars used in commercial production.

4.6 Geranium

Factors affecting quality of geranium cv Century Rose were described in detail in the previous report (Pearson *et al.,* 1995).

4.6.1 Effects of temperature on time to flowering

Figure 19 shows the effects of temperature on the time to flowering of 53 crops of geranium cv. Century Rose and 43 of cv. Multibloom White. This shows that as temperature increased time to flowering decreased, though the considerable scatter suggests that factors other than temperature affected time to flowering. Increasing temperature from 15 to 25°C decreased time to flowering from 120 to 80 days, whilst a small increase from12 to 15°C decreased time to flowering from 200 to 120 days. There were few differences in the responses of the varieties to temperature, though on average Multibloom White flowered a week earlier than Century Rose.

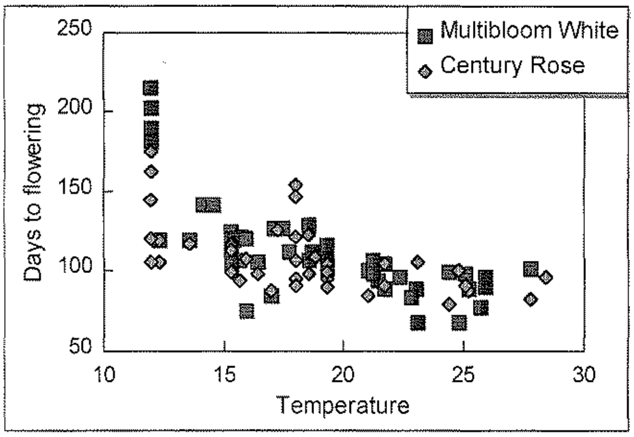


Figure 19. The effects of temperature on the time to flowering of geranium cv Multibloom White and Century Rose.

4.6.2 EFFECTS OF PHOTOPERIOD AND LIGHT INTEGRAL ON TIME TO FLOWERING

Figure 20 shows the effects of light integral on the time to flowering of geranium. This indicates that time to flowering is delayed considerably by a reduction in light level.

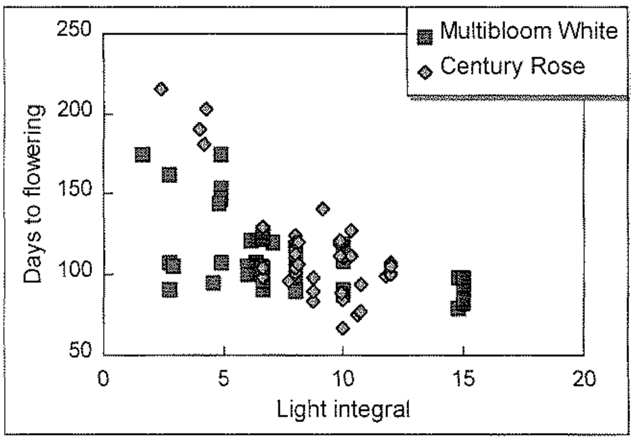


Figure 20. The effect of light integral ($MJm^{-2}d^{-1}$; total solar radiation) on time to flowering of geraniums.

Thus, at a light level of 2.5 $MJM^{-2}d^{-1}$ (January / February day) cv. Century Rose took 200 days to flower compared to 100 days at a light level of 10 $MJm^{-2}d^{-1}$ (April / May day). Century Rose appeared to be more sensitive to a reduction in light level than Multibloom White. For both varieties, photoperiod had no significant effect on time to flowering.

4.6.3 Scheduling Geraniums

All the data gathered during the study was combined into a single analysis to develop a relationship that predicts the effects of light integral and temperature on time to flowering of geranium. The relationship developed for Century Rose was (see appendix for diagrammatic representation);

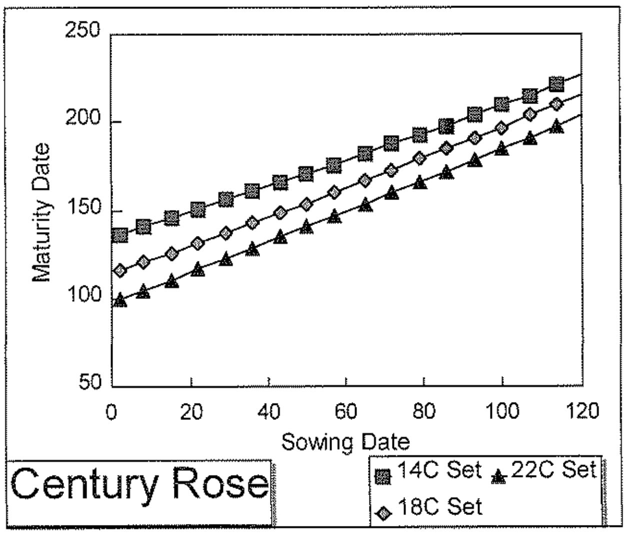
$1/f = 0.000824 + 0.000387T + 0.000158M$ ($r^2 = 0.65$, 50d.f.)

and for Multibloom White;

$1/f = 0.004351 + 0.000194T + 0.000202M$ ($r^2 = 0.58$, 39d.f.)

The relationships gave a reasonable description of the factors affecting flowering in geranium and were used to develop flowering date schedules according to the protocol described in section 4.1.3 (see Figure 21). The relationships indicate that increasing temperature and light integral reduce time to flowering.

21a



21b

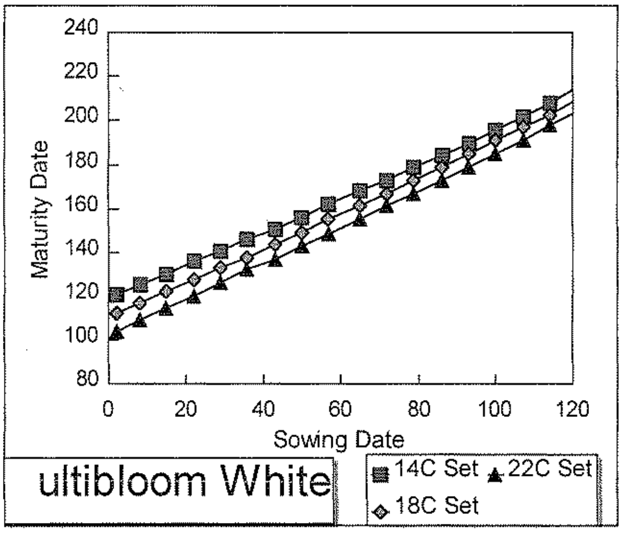


Figure 21a and b. Sowing date schedules for geranium cv. Century Rose and Multibloom White.

These schedules suggest that Multibloom White is less sensitive to changes in temperature than Century Rose.

5.0 CONCLUSIONS

This study has gathered considerable new information on the effects of environmental factors on the growth, quality and flowering of 6 of the key bedding plant species. Furthermore, the data has been quantified into a series of simple models that can be used to forecast flowering date given any set of environmental variables. These models have considerable application for crop forecasting, scheduling and for optimising crop production, and provide a framework for deciding on novel crop production strategies. Furthermore, in calibrating the models a great deal of information has also been gathered on the effects of environment on the quality of three previously non investigated species; antirrhinum, salvia and marigold.

Although in any study on plant scheduling it is not possible to examine the full range of varieties used in commercial production, this study has shown that all varieties tested, within a species, had similar responses to environmental variables. No significant variety x environment interactions were found, i.e. early and late varieties tended to be similarly 'early' and 'late' at all environmental combinations. This suggests that the schedules developed here would have wider application for scheduling a much greater range of varieties, since if a particular variety is known to flower a few days later or earlier than those scheduled here, then this difference is likely to be stable throughout the growing the season. The main exception would be Salvia, where some varieties are known to flower earlier in short days (Hughes and Cockshull, 1966); those tested here were found to flower earlier in response to long days.

The schedules reported here were developed using long terms average weather conditions for Reading. The accuracy of any schedule would no doubt be increased if it were tailored for the environmental conditions (outside air temperature, light integral, photoperiod and glasshouse light transmission) on individual nurseries. Towards this end the models developed here are now being incorporated into a computerised decision support program, which will be available to growers through the HDC. This program will use the models to schedule crops, forecast maturity dates of sown crops, determine how temperature can be manipulated to change maturity dates of batches and indicate likely space and product availability in different weeks. It will therefore provide a powerful management tool for bedding plant nurseries. The models are also now being applied in a further study to determine the most profitable growing temperatures for different bedding crops.

6.0 Acknowledgements

We wish to thank Stuart Coutts and Brian Crosby for their help and support for this project. We also thank David May (formerly ADAS) who helped to establish this work. MAFF funding for certain elements of the study is also gratefully acknowledged.

7.0 REFERENCES

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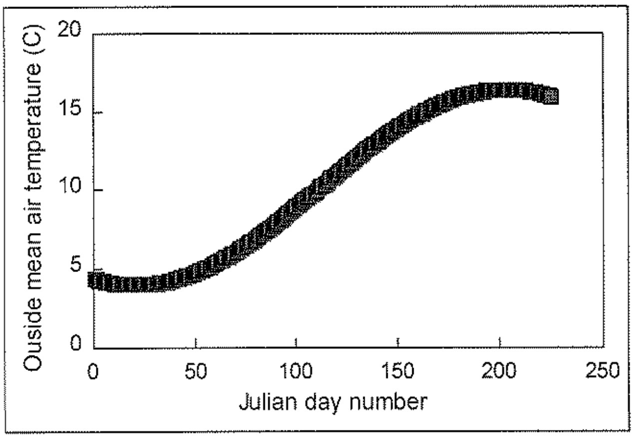
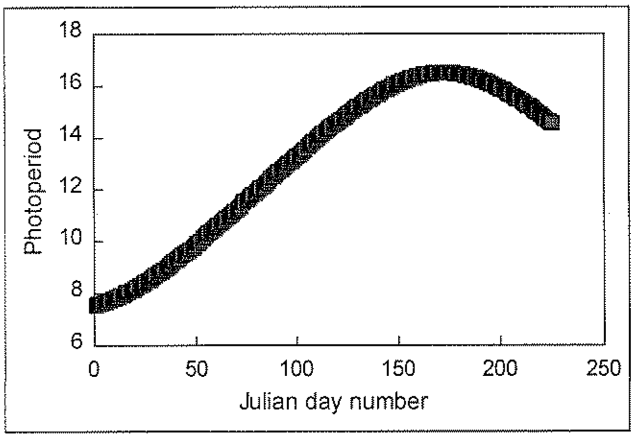
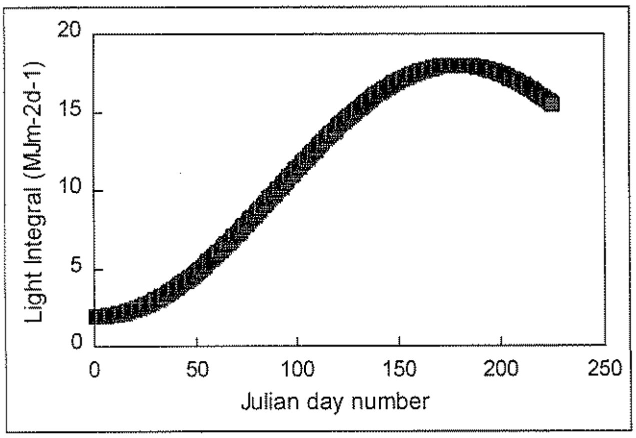
APPENDIX: OUTSIDE MEAN TEMPERATURES, PHOTOPERIODS AND LIGHT INTEGRALS USED IN THE DEVELOPMENT OF THE SOWING SCHEDULES.







APPENDIX: FLOWERING RESPONSES

ANTIRRHINUM

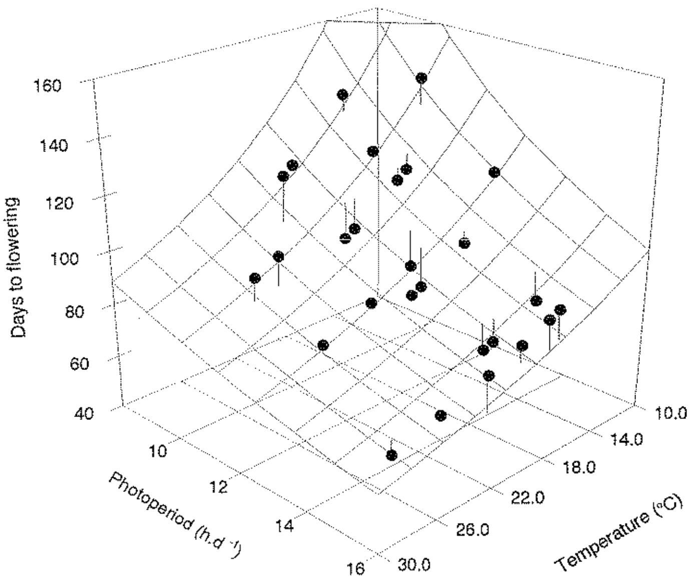


Figure 22. The effects of photoperiod and temperature on time to flowering of antirrhinum cv. Coronette Yellow. The curve was fitted by regression where $f = 1/(-0.00291+0.000319T+0.000529P)$, $r^2 = 0.71$, 24d.f.. Drop lines show the deviations from the fitted line.

SALVIA

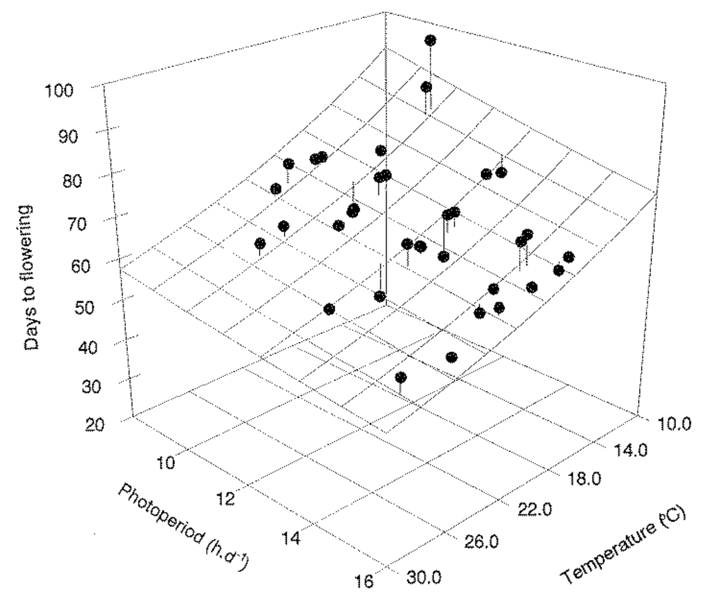


Figure 23. The effects of photoperiod and temperature on time to flowering of salvia cv. Sizzler Red. The curve was fitted by regression where;
$f = 1/(0.00545+0.000322T+0.000288P)$, $r^2 = 0.72$, 31d.f..

MARIGOLD

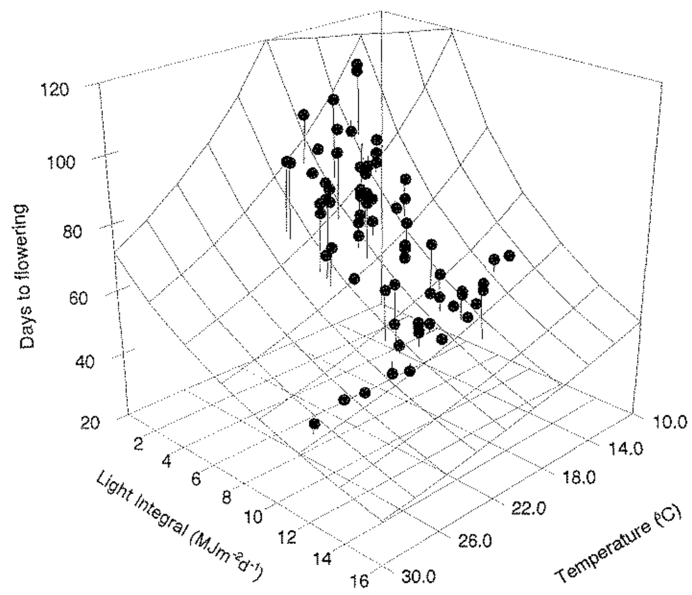


Figure 24. The effects of light integral and temperature on time to flowering of marigold cv. Yellow Boy. The curve was fitted by regression where;
f = 1/ (-0.00128+0.000508T+0.001009M), r^2 = 0.81, 72d.f..

IMPATIENS

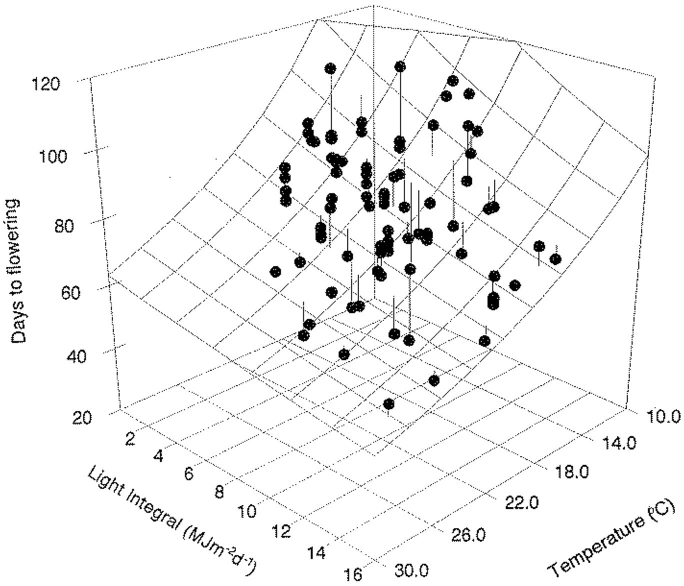


Figure 25. The effects of light integral and temperature on time to flowering of impatiens cv. Accent Red Star. The curve was fitted by regression where;
$f = 1/(0.001245+0.000486T+0.000245M)$, $r^2 = 0.68$, 79d.f..

PETUNIA

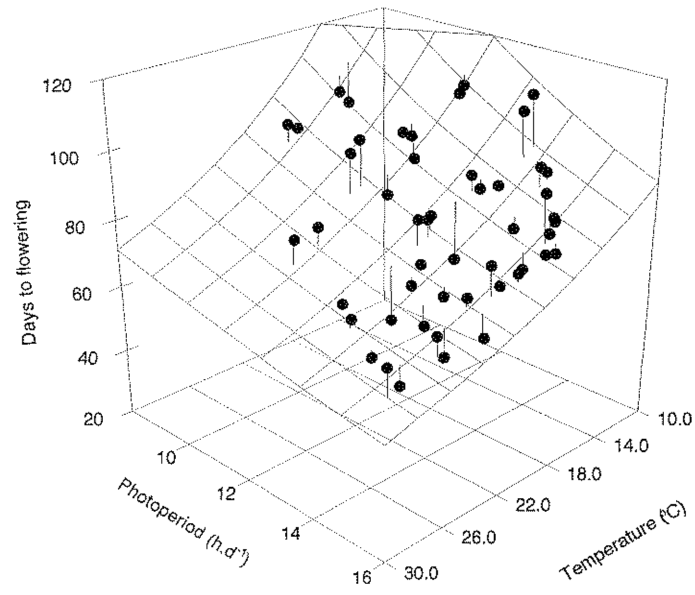


Figure 26. The effects of photoperiod and temperature on time to flowering of petunia cv. Express Blush Pink. The curve was fitted by regression where;
$f = 1/(-0.00202+0.000383T+0.000573P)$, $r^2 = 0.73$, 46d.f..

GERANIUM

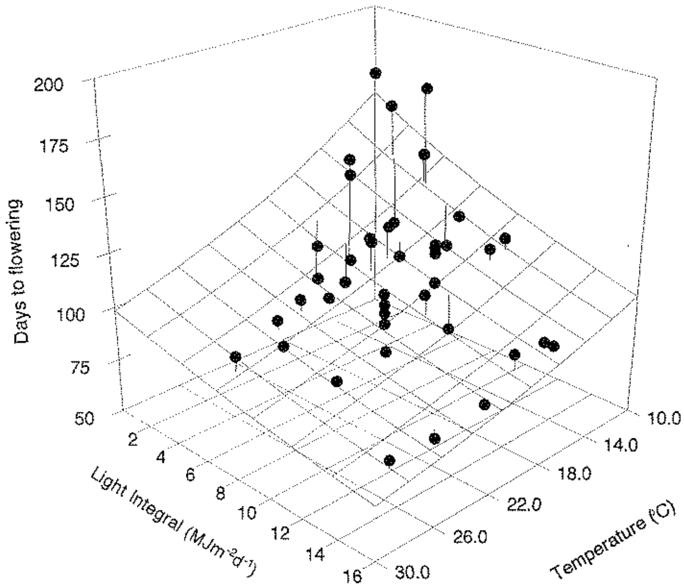


Figure 27. The effects of light integral and temperature on time to flowering of geranium cv. Multi bloom White. The curve was fitted by regression where;
$f = 1/(0.004351+0.000194T+0.000202M)$, $r^2 = 0.58$, 39d.f..