Project title:	Alstroemeria: Towards understanding and optimising productivity, quality and scheduling of Alstroemeria under UK commercial production conditions through monitoring and analysing data from grower holdings
HDC project number:	PC 205
Project leaders:	Mr Gordon Hanks, Warwick HRI, Kirton, Boston, Lincolnshire PE20 1NN (2003-2005) Dr Debbie Fuller, Warwick HRI, Wellesbourne, Warwickshire, CV35 9EF (2005)
Report:	PC 205 Final Report (2008)
Previous reports:	PC 205 Annual Report (2004), PC 205 Informal update report July (2005)
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Location:	Six Commercial Alstroemeria Nurseries.
Project co-ordinators:	Mr Bob Goemans, Parigo, Millfield Nursery, Spalding Common, Spalding, Lincs PE11 3JZ
Date commenced:	June 2003
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Keywords:	Alstroemeria, environment, irrigation, bed cooling/warming

Signed on behalf of: Warwick HRI

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Grower Summary

Grower Summary

Headline

This project showed the positive effect of regulating soil temperature in Alstromeria to improve crop yield and quality and also demonstrated that Evapometers were a reliable method of scheduling irrigation. More detailed work is required to establish the effects of supplementary lighting and environmental factors such as air temperature and humidity.

Background and expected deliverables

Commercial alstroemeria production requires a long term commitment with crops typically grown for 3 years. Factors influencing the production of marketable stems are complex. Stems harvested for marketing arise from rhizomes and hence future productivity is dependent on previous environmental conditions (irrigation / temperature etc). For example, flowers are initiated by low temperature and inhibited by higher temperature, and hence a rise in current temperature may speed up production of stems already developing but may inhibit the future production of flowering stems. This complexity and long crop duration, coupled with the wide range of varieties grown by UK growers makes experimental trials difficult and costly. The current project was devised to provide baseline information about UK production via a monitoring scheme which included 6 participating commercial sites. The aims of this scheme were to:

- Determine the key factors responsible for the high quality production that UK producers are recognised for and to then optimise these factors to further improve quality.

- Monitor soil temperatures in both winter and summer in a range of UK production units and soil types to assess the benefits of implementing soil cooling/warming facilities.

- Evaluate irrigation practice in relation to environmental parameters.

- Assess the benefits of supplementary lighting under UK conditions.

Summary of the project and main conclusions

- Regulation of soil temperature in Alstromeria cv Irenna:
    - Improved quality in summer and winter
    - Improved yield in winter
    - Reduced labour and waste associated with crop thinning
- Supplementary lighting of cultivars across the sites gave variable results and further work to determine optimal duration, intensity, thresholds is needed.
- Evapometer data correlated well with actual water use and could provide a suitable system for automated control of irrigation.
- It was not possible to relate short term changes in environment with future changes in yield by collecting total yield data from a range of sites. More detailed experimentation is likely to be required to make sensible predictions in the complex and variable cropping system.

Cropping patterns were monitored on six commercial nurseries in relation to environmental parameters from August 2003 to December 2005 with the aim of identifying trends from the data that would provide guidance of key environmental drivers of changes in yield and quality. 25 representative beds of alstroemeria were planted in 2002 or 2003 across the six participating sites with the following varieties represented (numbers in brackets indicated the number of sites growing each variety).

California (2), Fuji (2), Goa, Irena, Olga (2), Orange Queen (2), Rebecca (3), Saba (2), Senna, Tampa, Tobago (3), Tropicana (2), Valentine, Ventura.

Sites varied in terms of management methods and structures used as well as in geographic location. One site has a soil cooling/warming system (i.e. regulated soil temperature) installed and the benefits of this technique were assessed by monitoring yield from two beds of the variety Irenna at this site, one of which was uncoupled from the cooling/warming system (unregulated) in order to compare yield with and without the use of this system.

Bed temperature regulation was clearly effective in preventing soil temperature exceeding 15°C in summer 2004 (it was not used continuously in summer 2005) and also increasing soil temperature in winter 2004 (not used in winter 2005) as shown in figure 1.

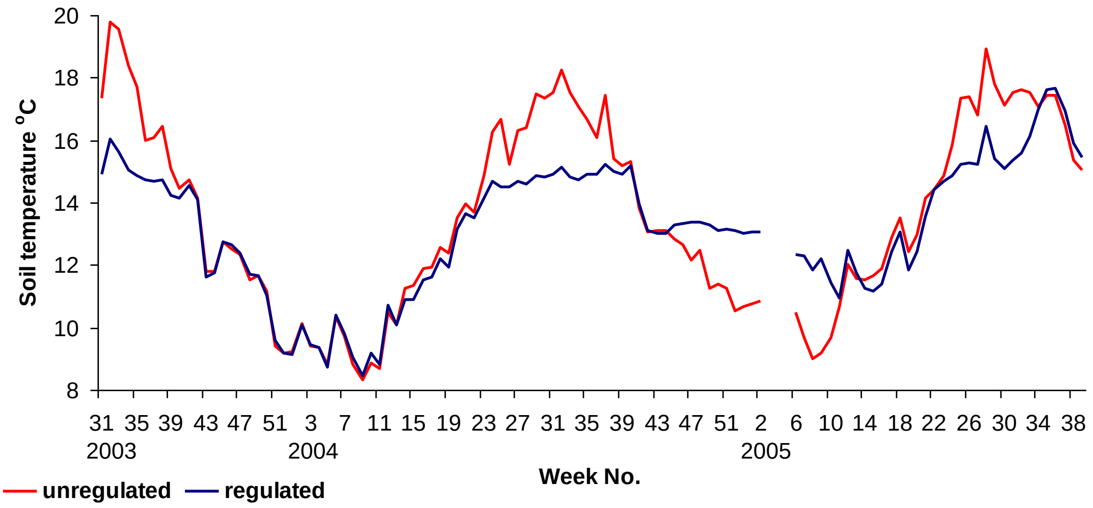

Figure 1

Whilst cumulative yield from the regulated bed appeared to be higher than from the unregulated bed, these differences were not statistically significant over the course of the whole experiment.

When data for yield was broken down into shorter seasonal periods, yield in the winter 2004/05 period was found to be significantly higher in the regulated bed by 2.3 stems/m², presumably due to the soil warming effect.

Soil temperature regulation however significantly improved the quality of harvested stems (figure 2). Quality was significantly better in the regulated treatments during summer 2004, autumn 2004 and winter 2004/5. The cooling system was turned off for parts of the summer 2005 period which may explain the lack of difference at this time.

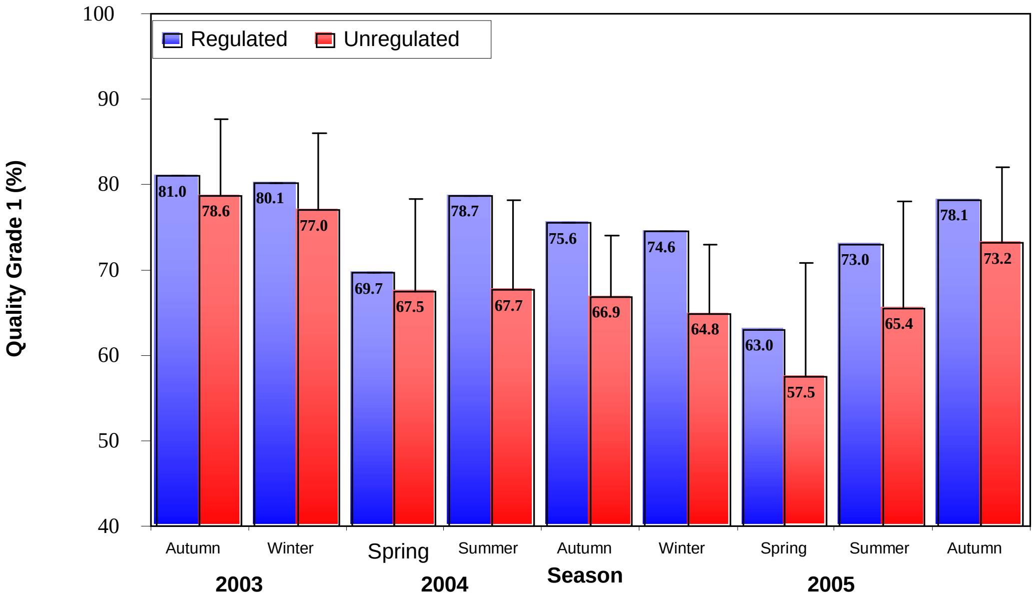

Figure 2

Regulating soil temperature was also beneficial in terms of reducing the labour and waste associated with crop thinning, with 149 stems/m² fewer stems removed for crop thinning from the regulated than the non regulated bed. Interestingly, the unregulated bed from the site with temperature regulation had the lowest soil temperatures of the six sites assessed and hence estimates of the benefits of the system are likely to be conservative from this comparison.

Comparison of trends from year to year suggested that supplementary lighting produced a small benefit in yield (around 10 stems/m² over 20 weeks) and a more notable improvement in quality of Orange Queen (with up to 71% grade 1&2 stems over the winter period compared with up to 38% for Rebecca grown without lighting) at one of the sites that used lighting in 2003/04. By contrast, California grown at this site appeared not to benefit from the lighting and also there were no apparent benefits from supplementary lighting at the other site that used it in 2003/04. Lighting would generally be expected to improve quality and/or yield or ornamental crops in the winter period, but settings such as duration of lighting per day, thresholds for turning the lights on and off and also the intensity of the lighting set up are all important parameters in achieving these benefits.

Analysis of water use data indicated that whilst irrigation had been triggered by radsum thresholds on two if the sites, Evapometer data had a better correlation with actual water use than radsum. Air temperature and relative humidity had little correlation with water use and would not be useful in either providing data to control irrigation or supplementing radsum or Evapometer data in order to improve their relationship with required irrigation. At the end of this project, one of the participating sites began to evaluate the use of an Evapometer to provide automated control of site irrigation which has potential to improve efficiency of water use.

Time series analysis was used to examine if fluctuations in environmental parameters such as air temperature could be used to explain the short term, week to week, variations in crop yield from a site. Since the stems harvested on any day will have been influenced by environmental conditions in previous weeks, the time series analysis looked for correlations between current yield and parameters between 1 and 8 weeks previously. Despite the obvious long terms effects of seasonal changes in environment on crop yield with the peaks in productivity in spring and autumn and the troughs over the winter, it was not possible to determine any simple relationships between specific environmental parameters and short term fluctuations in yield. That is, it was not possible from the data to predict what a sudden increase in temperature for example might have on yield over the forthcoming weeks. This sort of information would be valuable in managing nursery work flow and marketing, and may also be used for manipulation of productivity, but more controlled experiments are likely to be required for reliable predictions of yield to become possible.

Financial benefits

Data collected has demonstrated that regulation of soil temperature can be expected to benefit Alstroemeria production in the UK as it does in Europe.

Improvements in quality were found to be greater for the variety Irenna than improvements in total yield and this would have to be assessed against requirements of current/future market outlets. Soil temperature on all sites monitored exceeded the 15°C level that was maintained in summer in the temperature regulated system evaluated in this project. There are therefore potential benefits of installing such a system across a range of UK sites. Furthermore soil warming offers an energy efficient means of stimulating activity in crops during the winter.

Regulating soil temperature was also beneficial in terms of reducing the labour and waste associated with crop thinning, with 149 stems/m^2 fewer stems removed for crop thinning from the regulated than the non regulated bed.

The strong correlation found between Evapometer data and irrigation applied may give more growers the confidence to switch to an automated system which has potential to save labour and improve water use efficiency.

Attempts to correlate short terms changes in environment with subsequent changes in yield have not succeeded. More detailed experimentation is likely to be needed to determine models for suitable yield prediction.

Action points for growers

Consider installing a soil temperature regulation system to increase productivity and crop quality in summer through cooling and in winter through warming. Cost/benefit analysis should consider current nursery conditions, such as the length of time cooling may be needed (using previous soil temperature records) as well as the potential for increasing income based predominantly on quality improvements.

Consider the use of Evapometers or at least Radsum data for providing signals to trigger irrigation to either commence automated irrigation or to refine existing systems. Benefits should include reduction in labour, and through experimentation with set points, there is also potential to improve the efficiency of water use.

Where supplementary lights are in use it is important to check that the settings/intensity are providing sufficient benefit to justify running costs.

SCIENCE SECTION

INTRODUCTION

Alstroemeria is a perennial crop, purchased under licence as rhizomes and normally grown in the soil for three years before grubbing and replacing. This long crop duration and the wide range of varieties grown by UK growers make experimental trials difficult and costly.

The UK alstroemeria crop is currently valued at approximately £6 million in farm gate sales (BHS, 2006) and occupies a UK production area of about 16 ha. Following a discussion meeting with alstroemeria growers in 2000, the HDC funded a review of worldwide research and production practices on alstroemeria (HDC project PC 192). This review project suggested the several recommendations for further R&D and technology transfer work. `To follow up on these recommendations growers felt there was a need to build up research expertise on alstroemeria in the UK and the current project based on commercial holdings with established agronomic expertise was therefore established. Work objectives included:

> Monitor soil temperatures in both winter and summer in a range of UK production units and soil types to assess the benefits of implementing soil cooling/warming facilities.
>
> Determine the key factors responsible for the high quality production that UK producers are recognized for and to then optimize these factors to further improve quality.
>
> Evaluate irrigation practise in relation to environmental parameters.
>
> Assess the benefits of supplementary lighting under UK conditions.

A further component of this approach was to facilitate regular exchange of information with the Alstroemeria Study Group, which was planned to focus on experimental data but could also include information about related issues as appropriate. This would have the benefit of broadening interpretation of the data collected.

MATERIALS AND METHODS

General monitoring

Cropping patterns were monitored on six commercial nurseries in relation to environmental parameters over the period August 2003 to December 2006 with the aim of identifying trends from the data that would provide guidance of key environmental drivers of changes in yield and quality. 25 representative beds of alstroemeria were planted in 2002 or 2003 across the six participating sites as summarized in table 1.

Table 1: *Plant material used in the project*

Site code	*Cultivars*	*Planting date*
1	Fuji	January 2003
	Tropicana	February/March 2003
	California	January 2003
	Tobago	January 2003
	Saba	January 2003
2	Tobago	April/May 2002
	Rebecca	April/May 2002
	Tropicana	April/May 2002
	Olga	April/May 2002
3	Orange Queen	March 2003
	Rebecca	March 2002
	California	March 2002
	Valentine	March 2003
4	Fuji	May 2003
	Ventura	May 2003
	Goa	May 2003
	Tampa	May 2003
5	Orange Queen (soil cooled)	March 2003
	Senna (soil cooled)	March 2003
	Irena (soil cooled)	May 2003
	Irena (ambient)	May 2003
6	Rebecca	June 2002
	Tobago	June 2002
	Saba	June 2002
	Olga	June 2002

Crop agronomy for each experimental plot followed the standard procedures for each site; table 2 summarizes key features of the six sites participating.

Table 2: *Site details for the six nurseries participating*

	Site 1	*Site 2*	*Site 3*
Structure	30' mid-span glasshouse	21'-bay glasshouse	6.4m Venlo 3.5m gutter (Orange Queen) Simpson 5367 multi-span (Rebecca)
Soil type	Clay loam	Mid-loam with gravel/hoggin sub-soil	18" well drained peat soil over heavy clay
Irrigation method	Drip line	Drip + low-level spray line	Drip or overhead spray
Irrigation trigger	Radiation and time	Personal decision	Personal decision initially (later radiation sum)
Block area/ bed no.	1800m², 38 beds	1200m², 24 beds	4400m², 76 beds (Orange Queen) 682m², 15 beds (Rebecca)
Bed length, width	25.5 x 1.0m (39m²/bed)	26.0 x 1.0m (12 beds) (Tobago, Tropicana) 25.0 x 1.0m (12 beds) (Rebecca, Olga)	37.5 x 1.15m (Orange Queen) 23.2 x 1.2m (Rebecca)
Path width	0.5m	0.5m	0.5m (Orange Queen); 0.6m (Rebecca)
Plants per bed	140 (3.6 m^{-2})	121	210 (3.1 plants m^{-2}) (Rebecca)
Class I	5 heads, 85 cm (5 stems/bunch)	Strong, straight stem, 3-5 heads, 80 cm (consists of premium grade and grades 1&2).	Straight, strong stem, 70cm, 4+ heads, perfect leaves (in Dec. – Feb. can include some strong, 3+ headed flowers Class 2s)
Class II	4 heads, 70 cm (5 stems/bunch)	2 heads, 50-60 cm	Fairly straight, strong stem, 60cm+, 3+ heads, slight marking of leaves
Other class	Class 3: 3 heads (6-7 stems/bunch)	Not used	Not used
Waste:	Not specified	Very short, broken or very bent	1-2 heads, bent, damaged or no leaves, flowers too open

Thinnings:	Thin as picking	Thin separately (blind/very thin)	Thin separately (blind, bent, thin or weak)
Computer:	Hortimax	Hortimax	Hoogendoorn
Other factors:	Full, temperature-regulated misting programme	Supplementary lights available	Lights and screen in G15, neither in G3

Table 2 *(continued)*

Nursery	*Site 4*	*Site 5*	*Site 6*
Structure	Polytunnel	Double Venlo glass, 3 m post height	Venlo glass, 6.4 m-wide bays, 4 m height to gutters
Soil type	Very free-draining medium loam	Medium loam, well draining, some isolated clay patches on MUG	Sandy loam
Irrigation method	Drip line	Ground level spray lines	Drip line
Irrigation trigger	Radiation sum	Radiation sum, personal decision and time elapsed	Set times or personal decision
Block area/ bed no.	473m², 8 beds	n.a.	1254m², 24 beds
Bed length, width	115' x 2'8" (4.3 plants/m²) (Ventura) 115' x 3'3" (3.5 plants/m²) (Fuji, Tampa & Goa)	n.a.	24 x 1m
Path width	0.5m	n.a.	0.5m
Plants per bed	150 (Ventura); 180 (Fuji)	n.a.	72
Class 1	Strong stem, 5 heads, 85 cm ('stems')	Straight, 4+ heads, mid or tight bud, 80 cm	Straight, strong, 4+ heads, 80 cm
Class 2	Small 5s, and 3-4 heads, 70 cm ('bunches')	Weaker, 3+ heads, more open florets, 65 cm	Straight or slight bend, strong, 3 heads, 80 cm
Other class	Class 3: Bent/short 5s or 4s, and small 3s and 2s; 70 cm ('posy')	'Posy' class: any others	Short grade: 2 heads, bent stems that can be trimmed to bunches 55 cm
Waste:	Not specified	Not specified	Weak stems, badly damaged, old florets
Thinnings:	Thin separately (blind shoots)	Thin occasionally in autumn/winter (blind or broken stems)	Thin while picking or during other operations
Computer:	Priva	Priva	Volmatic/DGT

Other factors:	-	Soil cooling to 15°C from 1 month after planting, except for one area of Irene. Lights and screens available	-

Equipment was installed at each site to facilitate collection of the following environmental data:

Air temperature
Soil temperature
Relative humidity
'Gross transpiration' (via an Evaposensor*)
External radiation sum
Irrigation application (volume and frequency)
Soil moisture (Enviroscan or Netafilm)

*See HNS 97 project report for further details of this equipment.

The initial stages of the work involved site visits to ensure monitoring equipment and practices were comparable for each site and upgrading/installing equipment as required to ensure this was the case.

Crop yield and quality was continuously monitored manually by nursery staff who kept records of harvest data from each experimental plot. Since each site had its own quality grading system, data was collated into the broad categories listed in table 3 with data grouped as necessary to give a consistent comparison across all sites. Records were also kept of the number of un-saleable (waste) stems and stems removed for plot thinning.

Table 3: *Definition of flower grades used*

Revised class	Revised class definition	Original classes used by the six nurseries					
		1	2	3	4	5	6
1	80+cm long 4-5 heads	I	premium	} I	I	I	I
2	65+cm long 3-4 heads	II	I		II	II	II
3	Other saleable stems	III	II	II	III ('posy')	'posy'	'short'

Bed cooling/warming

Site 5 had a bed cooling/warming system installed throughout the nursery which allowed for a more detailed, single site study on the effects of this system. The cooling pipes were uncoupled on one bed of Irenna at this site and yield records kept of both this plot and of a second plot of Irenna grown in a comparable bed where the system continued to operate. Hence yield of Irenna grown in a bed with soil temperature regulation was compared with the yield of the same variety grown without soil temperature regulation at the same site.

Data analysis

Data were sent, electronically wherever possible, and in a standardised format, by the growers to FEC Services, where the data were validated and used to produce uniform Excel spreadsheet summaries for analysis by RISCU and Warwick HRI researchers. Summaries were also provided to the participating nurseries as appropriate.

Statistical analyses were performed to quantify the key environmental drivers of variation in production. The approach used was to correlate the explanatory variables (soil temperature, water, feed, etc.) against important response variables (yield and quality). This was achieved by fitting regression models relating the explanatory variables to a particular response.

RESULTS

Bed cooling/warming

For some components of the statistical analysis, data has been collated by season. For these purposes, seasons are defined as follows:

Season	***Months***	***Week Numbers***
Spring	February, March, April	05 - 17
Summer	May, June, July	18 - 30
Autumn	August, September, October	31 - 43
Winter	November, December, January	44 - 04

Soil temperature

The regulated treatment clearly lowered average weekly soil temperature during summer and autumn 2004 and 2005 and raised average weekly soil temperature during winter 2004/5 (figure 4). Where the system was operated throughout the summer period (summer 2004), the cooling system maintained soil temperature at around 15°C whilst the unregulated bed fluctuated between 15 and 18°C. Temperature in the regulated bed was less stable in the summer of 2005 when it was sometimes necessary for the site to turn the system off. Soil warming in the winter 2004/05 maintained soil temperature at around 13°C compared with temperatures falling to 9°C in the unregulated bed. Coupling summer cooling with winter warming therefore has the potential to provide a more consistent year round temperature than beds without temperature regulation.

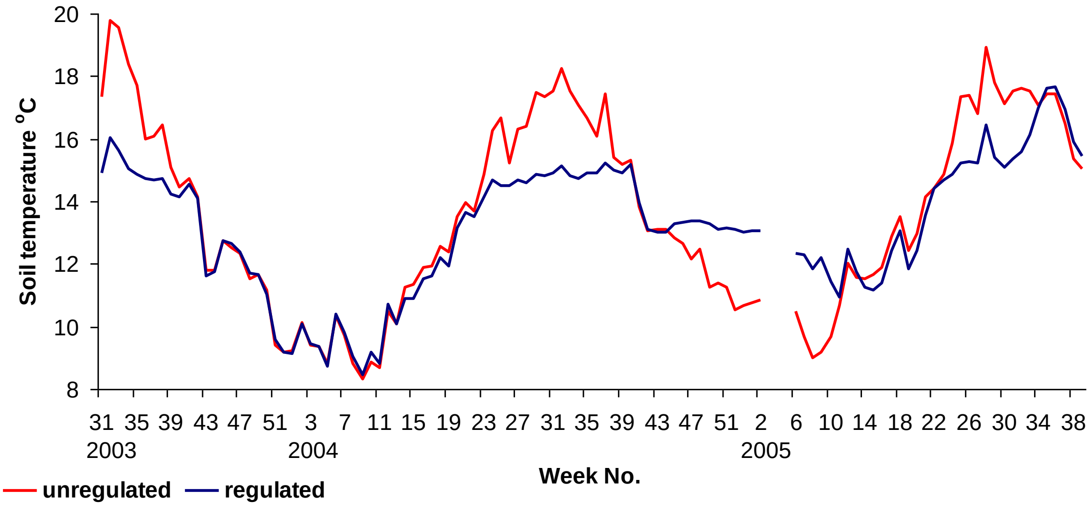

Figure 4: *The influence of regulating soil temperature with a heating/cooling system on achieved bed temperature*

Soil temperature data were formally analysed by collating the data into the seasonal periods outlined previously. Temperature regulation significantly reduced weekly average soil temperature during late summer and autumn 2004 and 2005 by around 1°C and significantly raised weekly average soil temperature by a similar amount during winter and early spring 2005 (figure 5).

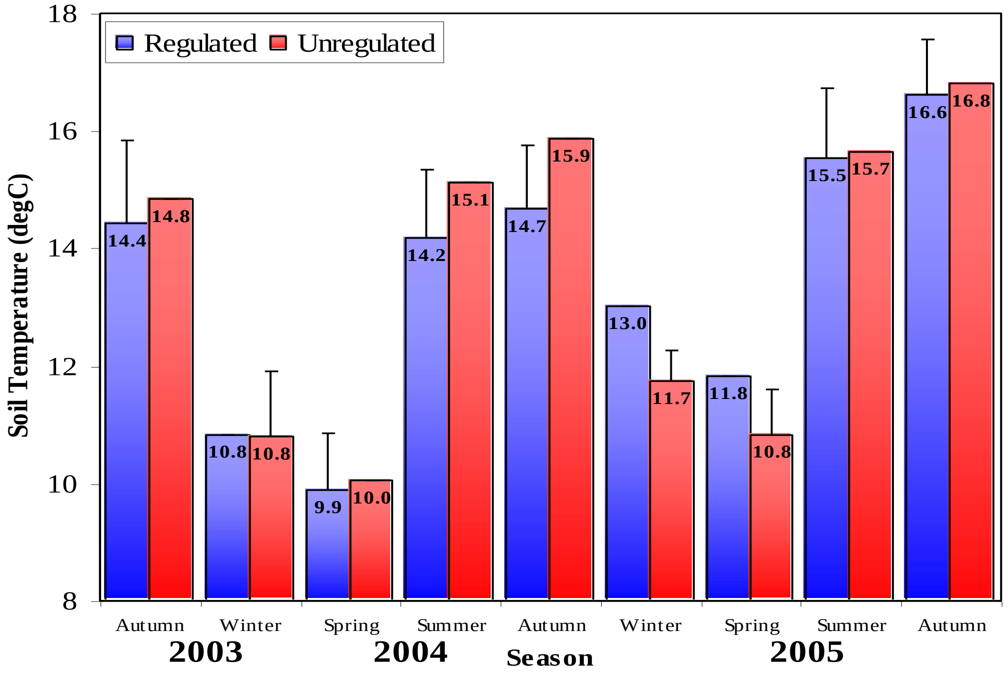

Figure 5: *The influence of regulating soil temperature with a heating/cooling system on seasonal bed temperature*

Total Yield

Total weekly yield of marketable stems was similar for the regulated and unregulated beds for the start of the experiment up to around week 28 in 2004. Some differences in weekly yield were apparent on occasion between the two treatments (figure 6). Yield data was analysed further by examining cumulative yield over the duration of the trial. The difference in cumulative yield between regulated and unregulated plots of the variety Irenna suggests a benefit of temperature regulation (figure 7).

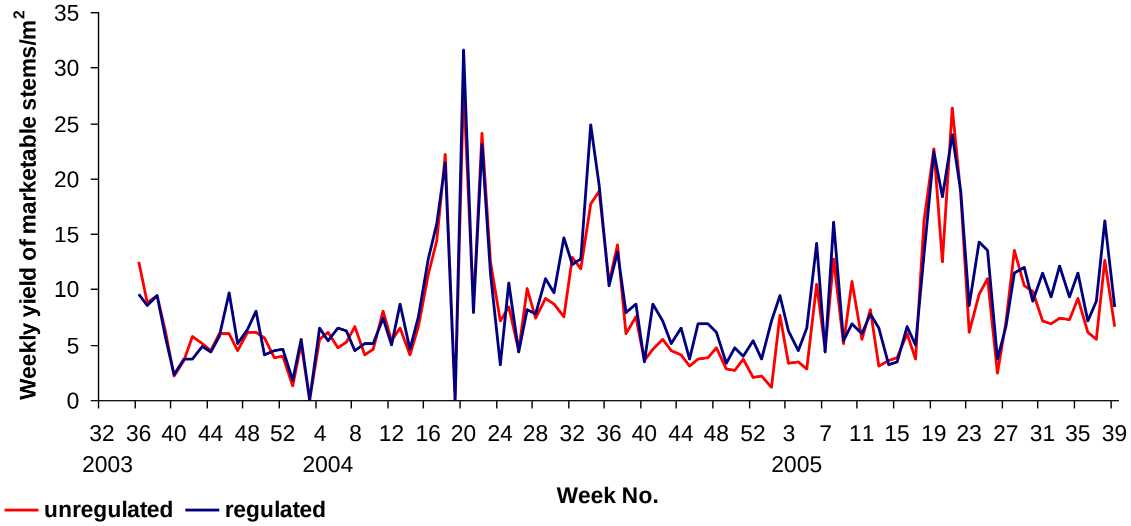

Figure 6: *The influence of regulating soil temperature with a heating/cooling system on yield of total marketable stems of the variety Irenna*

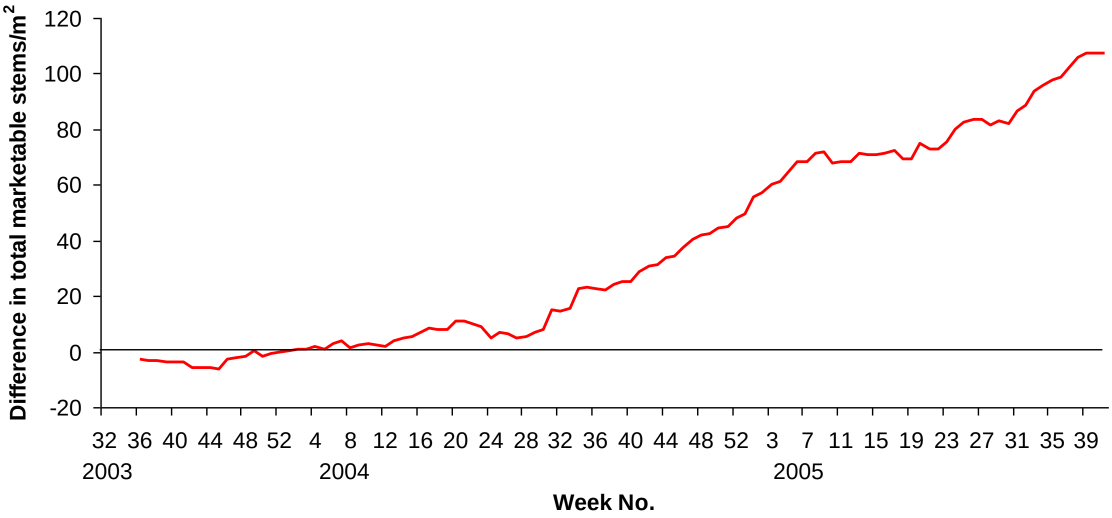

Figure 7: *The influence of regulating soil temperature with a heating/cooling system on the difference in cumulative yield between regulated and unregulated beds of the variety Irenna*

Total yields, over the 110 weeks from week 36 in 2003 to week 41 in 2005, for the regulated and unregulated treatments were 945 and 838 stems/m^2 respectively. This means there was an additional yield from the regulated plots of 107 stems/square metre which is equivalent to a yield benefit of 1.0 stems/m^2 per week averaged over the duration of the trial. Since rhizome density is considered to be important in response to soil cooling/warming, it may be more appropriate to calculate the average yield benefit from week 30 in 2004, when the effect of cooling on yield becomes more apparent. On this basis, the regulated treatment produced 99 more stems over 64 weeks which is equivalent to 1.5 stems/m² per week.

Analysis of the cumulative weekly yield data (figure 8) indicates that the yield difference was consistently positive from midway through 2004 indicating a greater yield for the regulated treatment. The difference between the regulated and unregulated plots however was never greater than the least significant difference for each weekly average yield figure. In summary, as the data for difference in yield did not cross the lines indicating least significant difference, one must conclude that, given the large week-to-week variability in yield, the difference can not, over the course of the whole experiment, be considered significant.

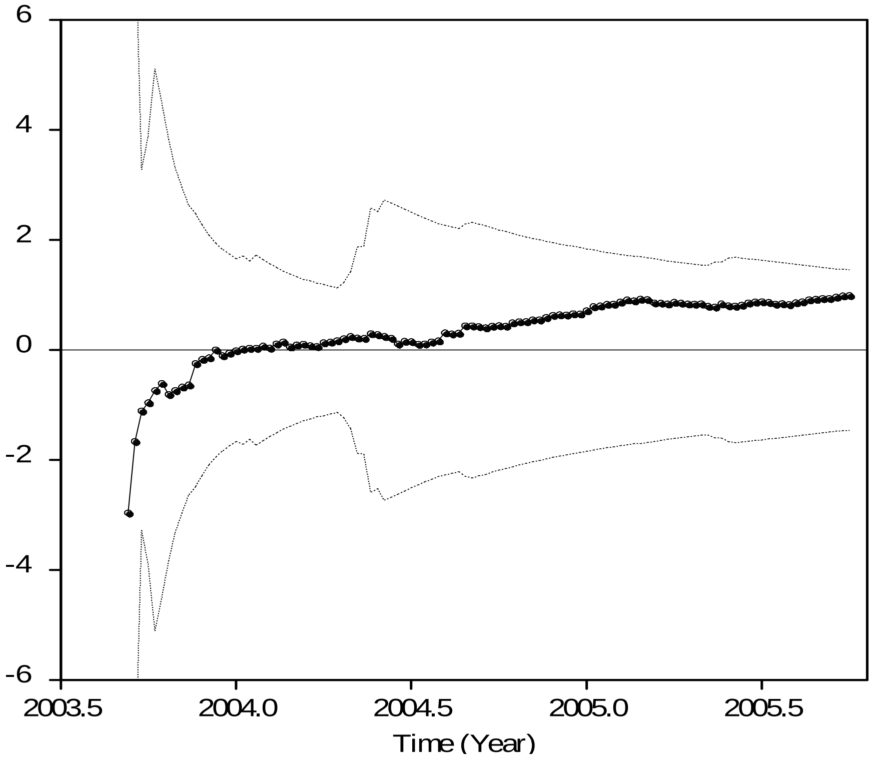

Figure 8: *The influence of regulating soil temperature with a heating/cooling system on difference in weekly yield between treatments (calculated on a cumulative basis) of the variety Irenna (dashed lines indicate least significant difference for each data point)*

Although differences in yield were not found to be significant over the whole period of the project, a significant benefit was found if the data was collated into seasonal periods (figure 9). That is, yield in the winter 2004/05 was significantly higher in the regulated bed at 6.0 stems/m² (presumably due to the soil warming effect) than in the unregulated bed at 3.7 stems/m². There were however no direct significant effects of the soil cooling system on summer or autumn yield. It would be interesting to assess if the summer cooling effects had enhanced the winter warming effects but it is not possible to evaluate this from the data given the design of the current experiment.

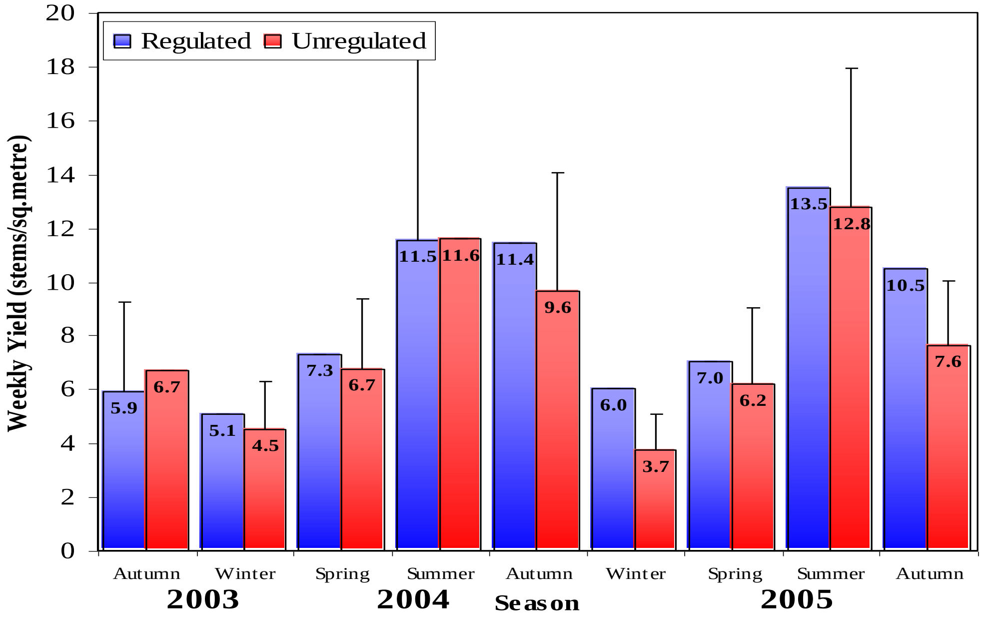

Figure 9: *The influence of regulating soil temperature with a heating/cooling system on seasonal yield of the variety Irenna*

Quality

Despite the relatively small impact on total yield as discussed above, regulating soil temperature was found to improve the quality of stems harvested (figure 10).

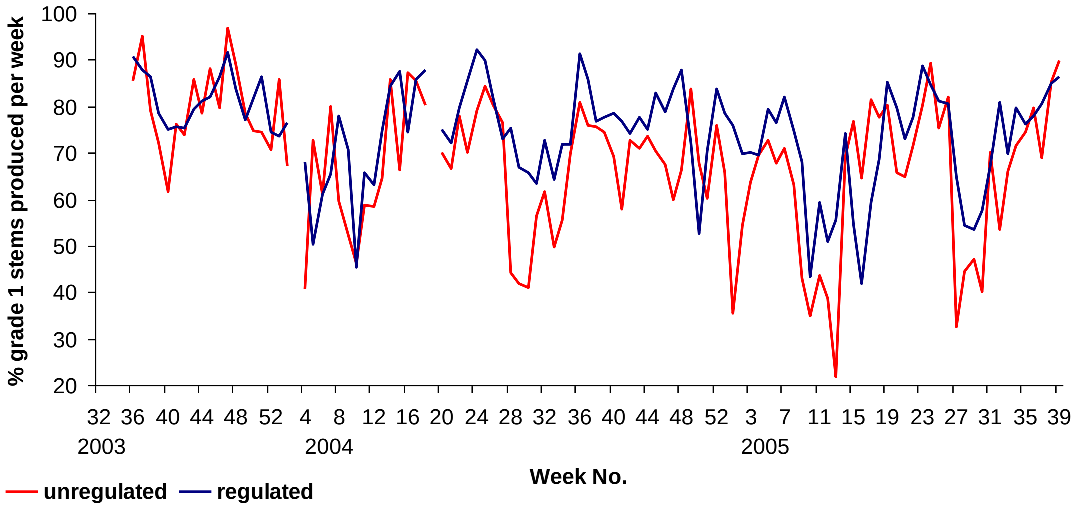

***Figure 10:** The influence of regulating soil temperature with a heating/cooling system on % grade 1 stems produced of the variety Irenna*

The regulated bed consistently produced an average of 5% more grade one stems in the cumulative yield data over the duration of the trial (figure 11).

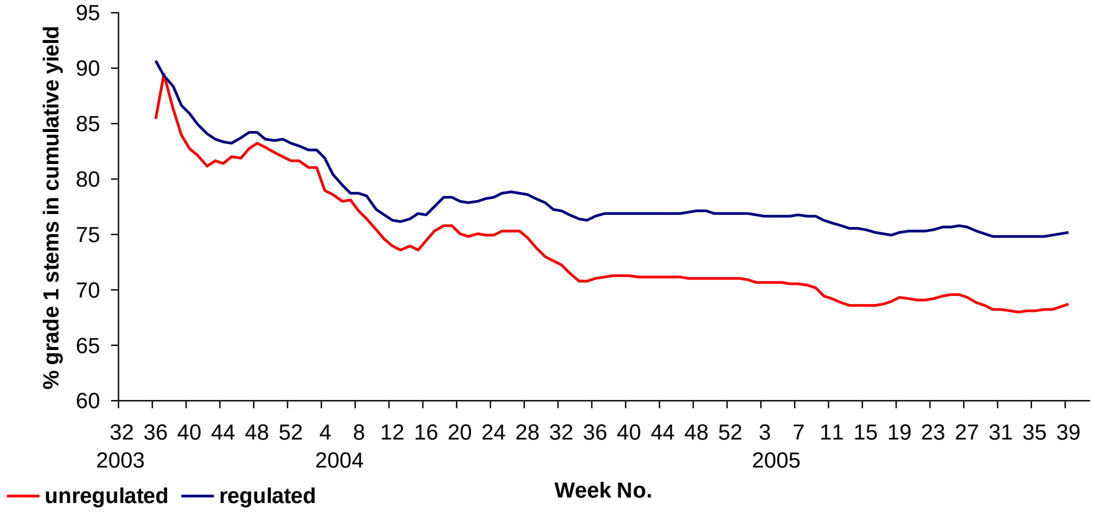

***Figure 11:** The influence of regulating soil temperature with a heating/cooling system % grade 1 stems in cumulative yield from the variety Irenna*

The trends discussed above are re-enforced by the statistical comparisons made where the regulated bed produced a significantly higher percentage grade 1 stems from the start of the trial, and from mid-2004 onwards, the increase in %grade 1 stems produced was greater than the weekly figures of least significant difference, indicating that quality was significantly greater for the regulated than the unregulated treatment (figure 12). The data suggests that during the period under study, the regulated treatment had >5% more grade 1 stems than the unregulated treatment.

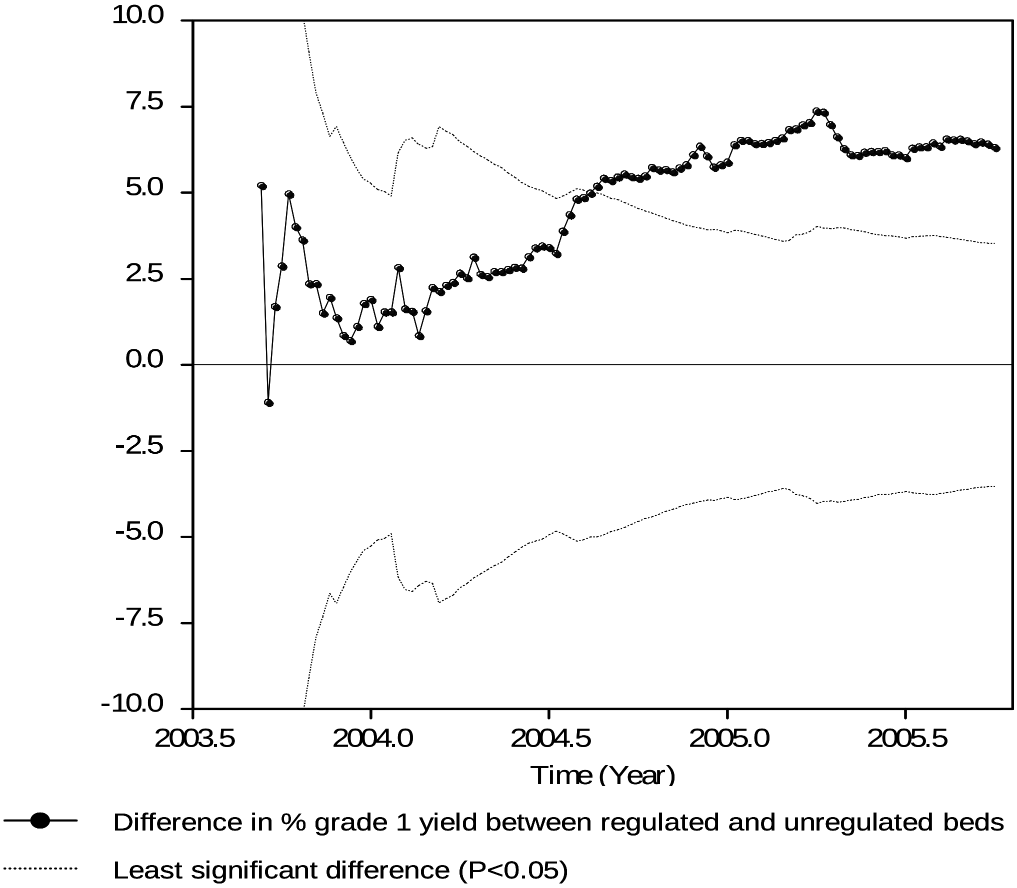

Figure 12: *The influence of regulating soil temperature with a heating/cooling system on the increase in % grade 1 stems (calculated in a cumulative basis) produced by the variety Irenna*

Significant differences in % grade 1 stem production were also found in the data collated according to season (figure 13). Quality was significantly better in the regulated treatments during summer 2004, autumn 2004 and winter 2004/5. Taken together, there is strong evidence of improved stem quality in the soil temperature regulated treatments.

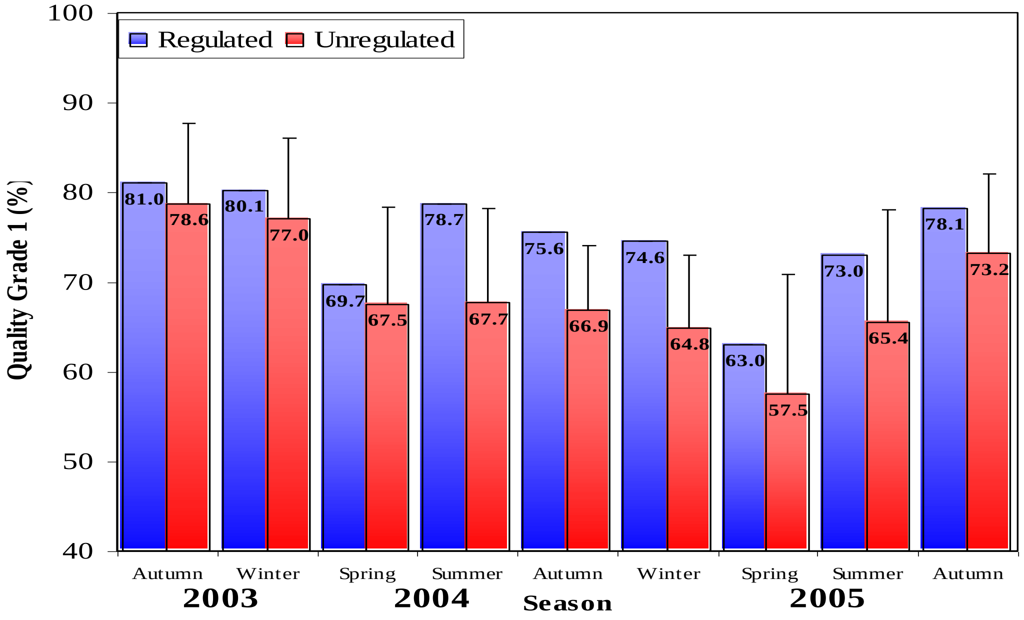

Figure 13: *The influence of regulating soil temperature with a heating/cooling system on seasonal quality for the variety Irenna*

Thinnings

The total number of stems removed by thinning from the regulated and unregulated treatments were summarised by season (table 4). Analysis of variance shows that, allowing for the large seasonal variation, there was significantly less (P<0.05) stems removed through thinning in the regulated treatment than in the unregulated treatment. Frequency of thinning was comparable in all treatments but this was often governed by other practical considerations on the nursery rather than by the need of individual plots.

Table 4: *Total numbers of thinned stems per square metre from regulated and unregulated treatments by season*

		Regulated	Unregulated
2003	Autumn	25.4	30.5
	Winter	18.3	22.3
2004	Spring	18.6	0.0
	Summer	30.0	35.2
	Autumn	40.0	74.1
	Winter	13.9	26.7
2005	Spring	53.1	134.6
	Summer	27.4	36.0
	Autumn	31.1	47.9
Total		258.0	407.2

Comparison of soil temperature regulation with ambient bed temperatures

On nurseries without soil cooling, average soil temperature rose above 15°C between weeks 21 and 41 across the three years of monitoring (figure 14) and peaked at around 19 to 20°C.

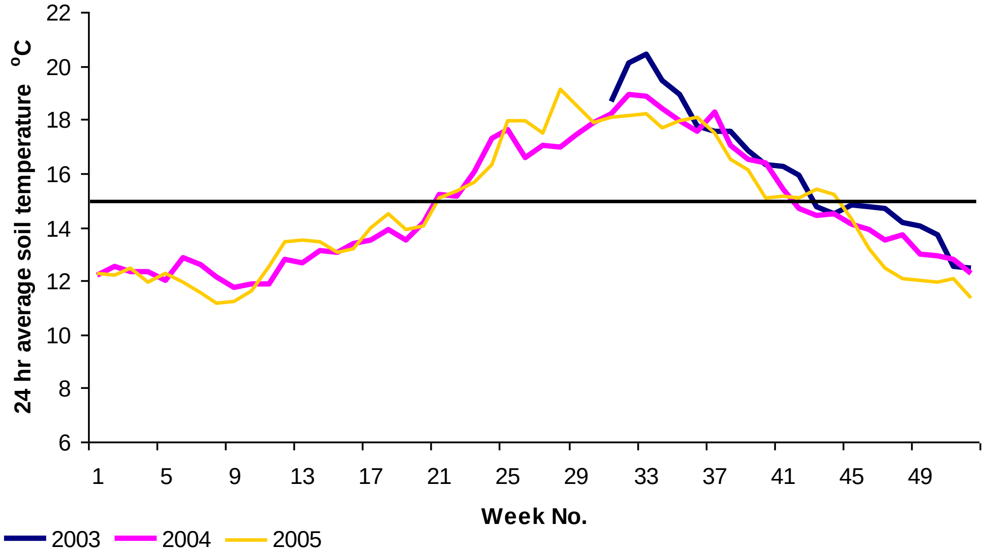

Figure 14: *Average soil temperature for all sites excluding data from cooled beds*

There were site to site fluctuations within these site averages, and whilst some nurseries experienced high soil temperature for up to 23 weeks of the year, others suffered these high temperatures for 8 to 12 weeks a year (table 5). Interestingly data from the site 5 bed that was not cooled were amongst the lowest for soil temperature in unregulated beds of the sites assessed. It would therefore appear likely that the other nurseries assessed might expect to achieve greater benefits from soil cooling than has been indicated here from the data collected from site 5. Soil temperatures at site 3 were at 16°C or greater for 40 to 44% of the year and hence this site would appear most likely to benefit from soil cooling out of the 6 sites assessed.

Table 5: *Number of weeks per year where average soil temperature was 16°C or greater (* represents un-cooled beds from the site with soil cooling installed). [1]Note data collection started in week 31 in 2003 and hence these data do not cover the start of the summer period*

Site	2003[1]	2004	2005
1	12	19	8
2	no data	no data	no data
3	21	22	23
4	12	16	14
5*	7	13	13
6	6	19	12

Irrigation management

Average water use across the 6 sites ranged from around 20 to 25 l/m² per week in summer to 5 l/m² in winter (figure 15). Bed flushing in the summer of 2004 at two of the sites resulted in an artificially high peak in weeks 28 to 30).

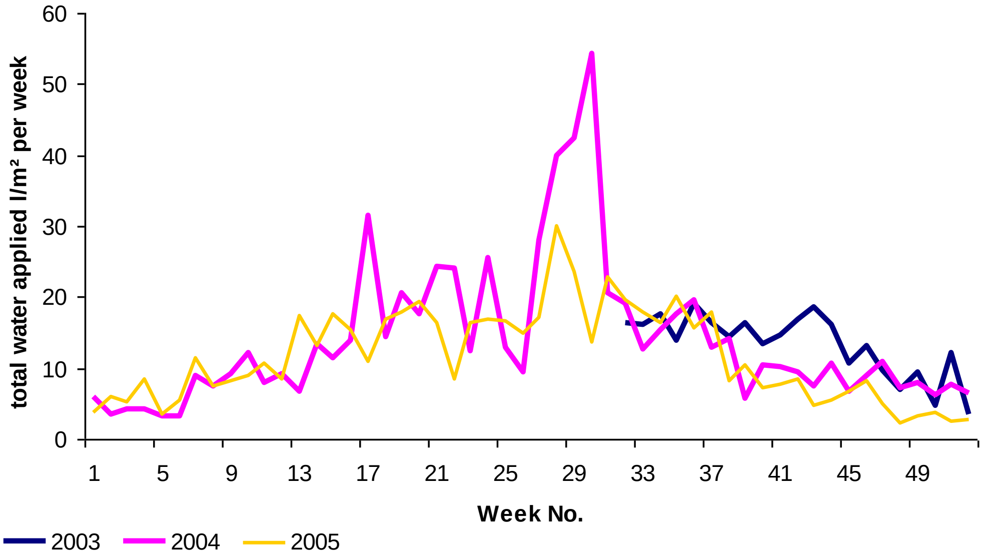

Figure 15: *Average weekly water used across 6 sites*

When water use by individual sites was compared against the average for all sites, it appeared that sites 1 and 4 had less week to week variability in water use than the other sites assessed (figure 16). Sites 1 and 4 were also considered to have a greater focus on irrigation management and have experimented with soil moisture sensors which may explain this difference in irrigation management compared with the other sites assessed.

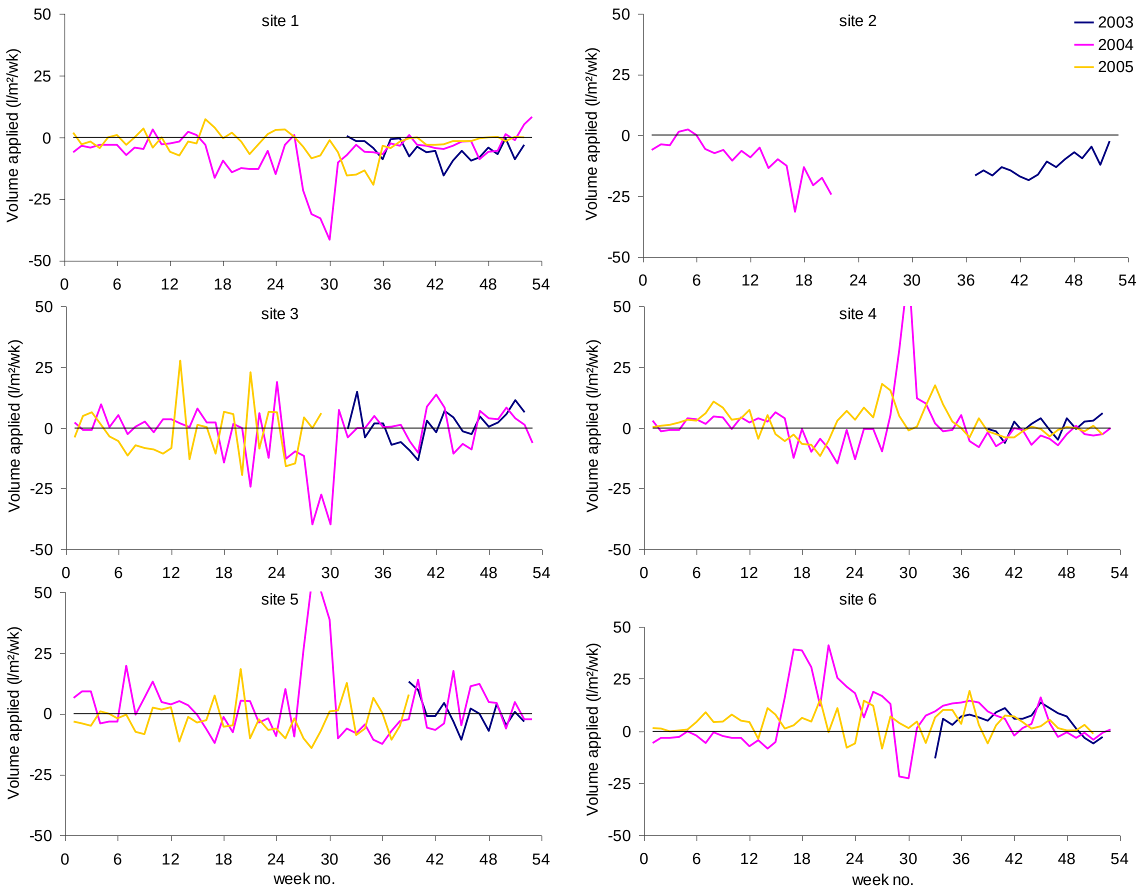

Figure 16: *Difference between individual site water use and mean use across all sites*

Statistical analyses were carried out in order to determine if it is possible to predict the actual water use applied according to environmental data recorded. As noted above, sites 1 and 4 had the greatest focus on irrigation control and hence data from these two sites were used in these analyses. Trends in water use were compared with factors that may influence these data i.e. evapometer data, air temperature, radiation sum and relative humidity (figure 17). There were a small number of large (~100l/m²) weekly water use values for site 4 during summer 2004 when beds were flushed and these atypical data were excluded from the analyses (these data points extend beyond the range of the axes in the graphs presented and have been excluded from the graphs in order better clarity of the remaining data).

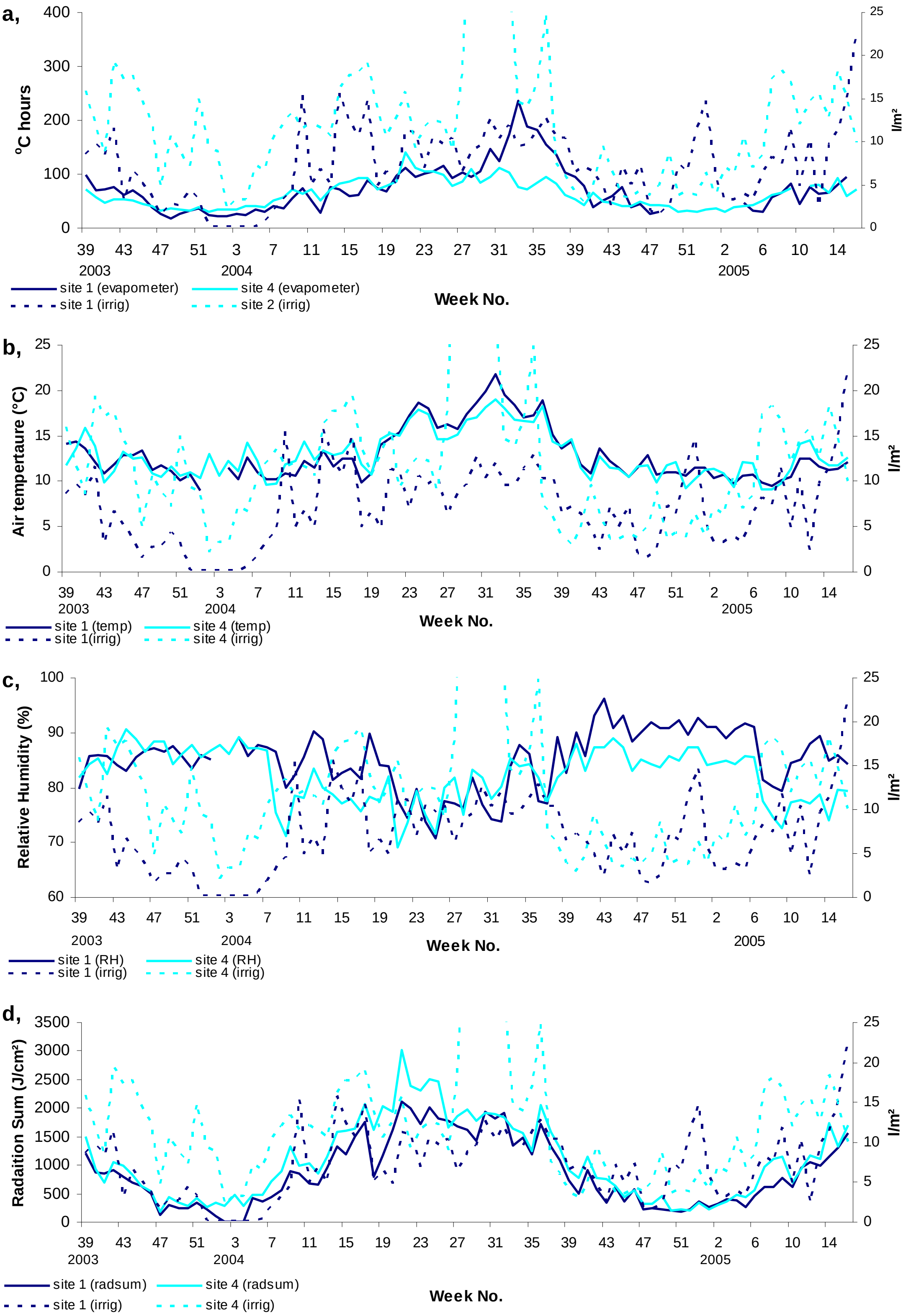

Figure 17: *Water use data compared with evapometer data (a), air temperature (b), relative humidity (c) and external radiation sum (d) from two nurseries from week 39 2003 to week 16 in 2005*

Trends in the raw data indicate an association between water use and all of the environmental variables and formal testing of the relationship between water use and each environmental variable was made by fitting an appropriate statistical model relating water use to each of the environmental variables in turn. The form of the model was approximately determined by plotting each environmental variable against water use in turn. The relationships shown for relative humidity and air temperature were weak, and a simple linear (straight line) relationship was chosen to model water use (figures 18 and 19).

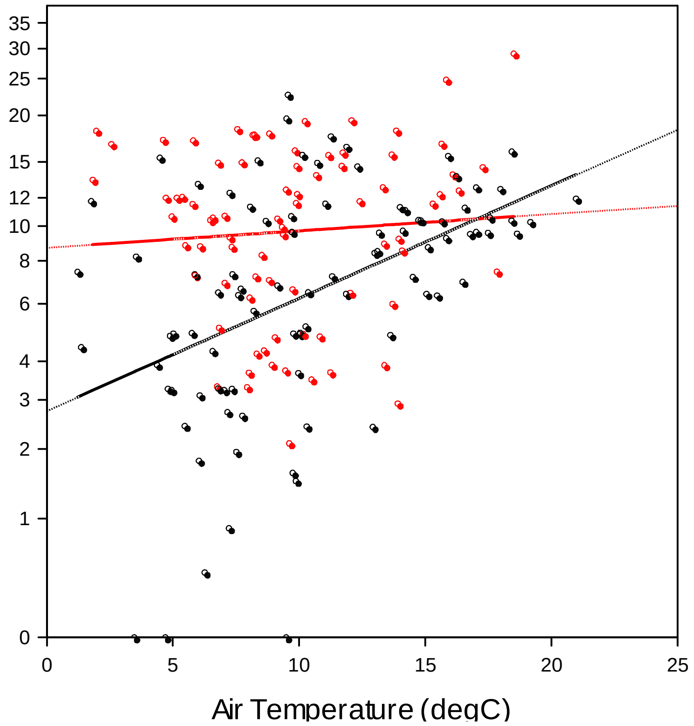

Figure 18: *The relationship between water use and weekly average air temperature for 2 commercial Alstroemeria producers (black points represent site 1 and red points represent site 5)*

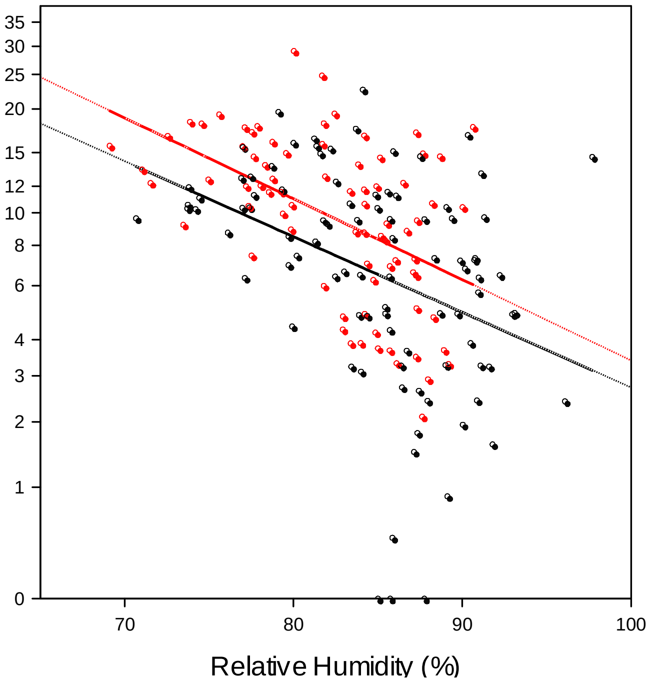

Figure 19: *The relationship between water use and relative humidity for 2 commercial Alstroemeria producers (black points represent site 1 and red points represent site 5)*

The relationships for evapometer and radsum data were more complicated and required a more complex non-linear function that was constrained to pass through the origin to model the relationship with water use (figures 20 and 21). These latter model relationships (figures 20 and 21) between water use and evapometer and radsum, appear to be a reasonable fit.

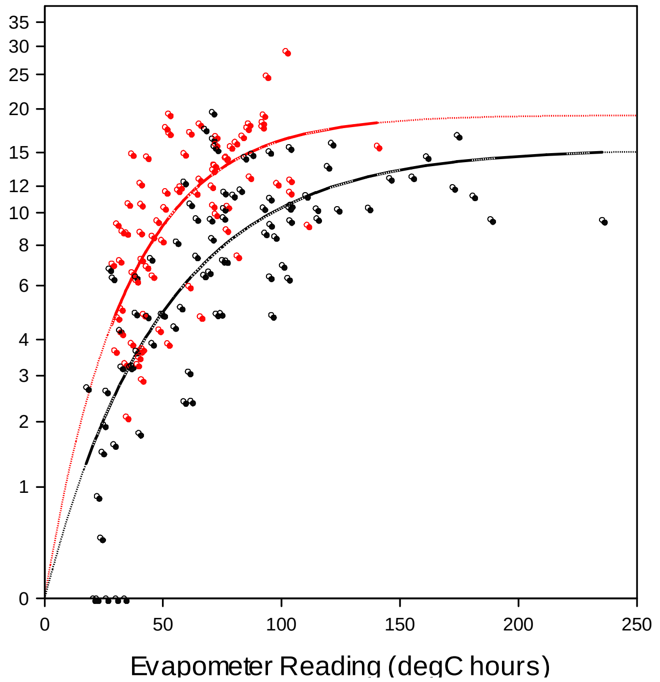

***Figure 20:** The relationship between water use and evapometer data for 2 commercial Alstroemeria producers*

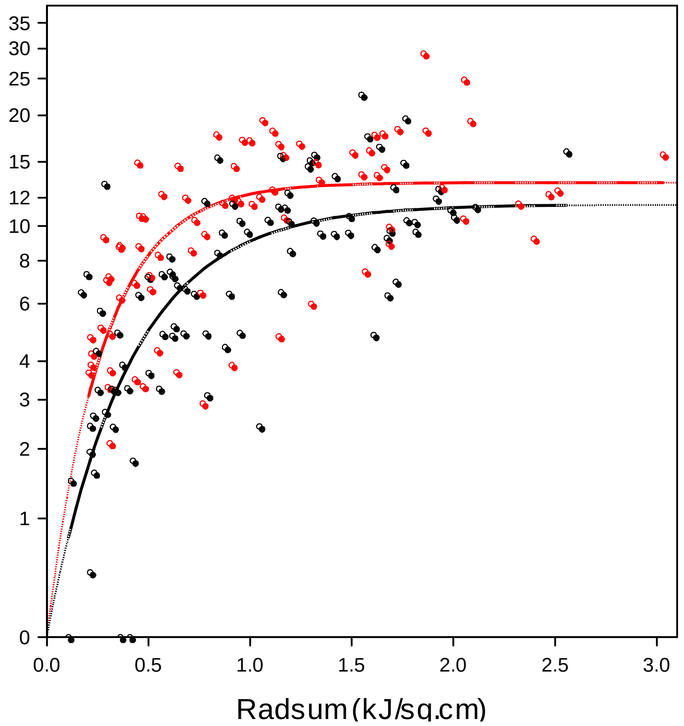

***Figure 21:** The relationship between water use and radiation sum for 2 commercial Alstroemeria producers*

Fits for each of these data sets were assessed by comparing the percentage of the variation in water use accounted for by each of the fitted models. A value of 100% would suggest a perfect model fit (i.e. weekly water use would be exactly predictable given appropriate environmental data) and a value of 0% would suggest a useless model (i.e. knowledge of the environmental variable would be of absolutely no benefit in predicting weekly water use). The percentage of variation in the data accounted for by the fitted models was small for both air temperature and relative humidity (table 6) which indicates that these measures, taken separately, are of not much practical use in predicting weekly water use. However, the values for evapometer and radsum data (with 43 to 62% of the variation in the data accounted for by the model) suggest that these measures do possess power to predict weekly water use. In the case of radsum data, this fit is to be expected as both sites used radsum to trigger irrigation but evapometer data was recorded independently of the irrigation control and gave a better fit than that for radsum.

Table 6: *Percentage variation (%) in water use accounted for by models based on evapometer, radsum, relative humidity and air temperature data*

Rank	Measure	Site 1	Site 2
(1)	Evapometer (°C hours)	61.7	45.4
(2)	Radsum (J/cm^2)	52.1	42.8
(3)	Relative Humidity (%)	14.5	24.3
(4)	Air Temperature (°C)	20.2	0.5

This modelling work has established that evapometer and radsum data recorded individually have power for predicting actual weekly water use; with evapometer proving to be the most important single measure even though it was radsum that was used to trigger irrigation. Additional modelling work indicated that where evapometer records are available, the other measures provide no significant additional power in predicting water use. This is probably due to the strong correlations between these factors, e.g. the correlation between evapometer and radsum readings was 0.709 and 0.957

for the two sites. Hence, evapometer readings provide the best single measure for predicting water use; supplementing this data with other records (radsum, relative humidity and air temperature) would not apparently add further benefit to the prediction of water use.

Relationship between yield and environment

As growers already recognize, there is a seasonal trend in yield with peaks in productivity coinciding with the summer and autumn periods indicating the importance of ambient environment (figure 22a) on stem production. There is also variability in yield from site to site which is best represented in a plot of overall mean with 95% confidence interval limits (figure 22b).

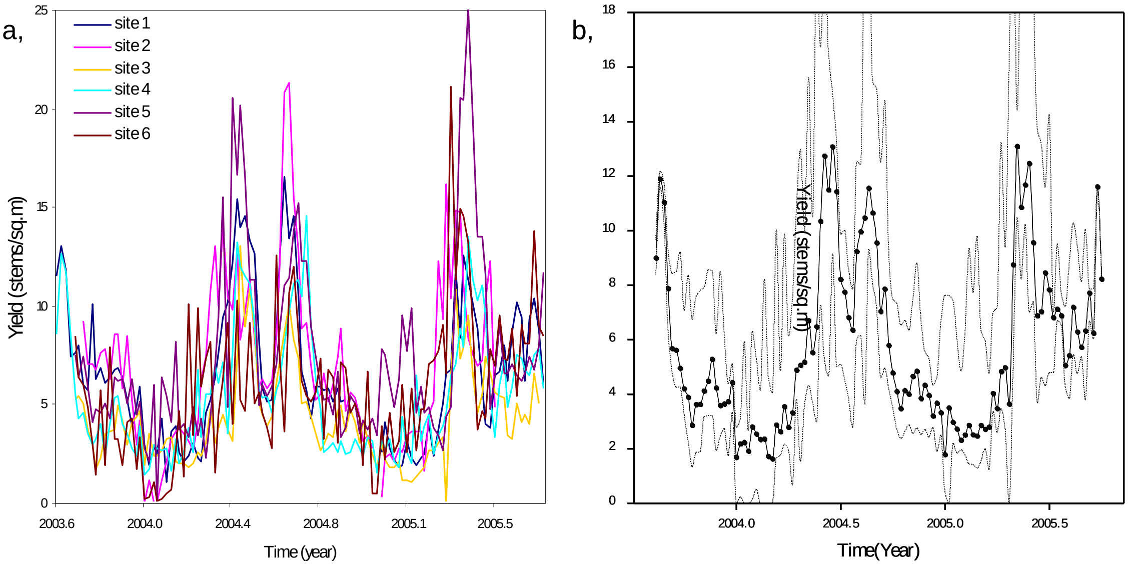

***Figure 22**: Trends in yield (stems/m²) for all sites [a] and averaged across sites [b] (where 95% confidence interval is plotted as dashed lines)*

The main sources of variability in yield data were considered to be:

(i) Long period seasonal trends
(ii) Shorter period cultivation and crop management cycles
(iii) Environmentally induced effects

There is a sinusoidal trend apparent on an approximately yearly time-scale which relates to the long period seasonal effects on the data. Superimposed on these longer term effects there is variability in yield from week to week that may be due to shorter period cultivation and crop management cycles, or environmentally induced effects, or neither. To investigate this, variability due to long period seasonal effects were first removed from the data by 'de-trending' which involved fitting a sinusoidal curve to model the yearly variability in overall mean yield.

It was difficult to model the yield during the mid-year peaks, and so yearly data was sub divided into two test periods which were 45 and 42 weeks long, from week 32 in 2003 to week 24 in 2004 and week 33 in 2004 to week 22 in 2005 respectively. The data was modelled by two fitted curves, which accounted for 82% and 80% of the variability (figure 23a) and then de-trended (figure 23b) leaving data which was no longer influenced by long term seasonal trends.

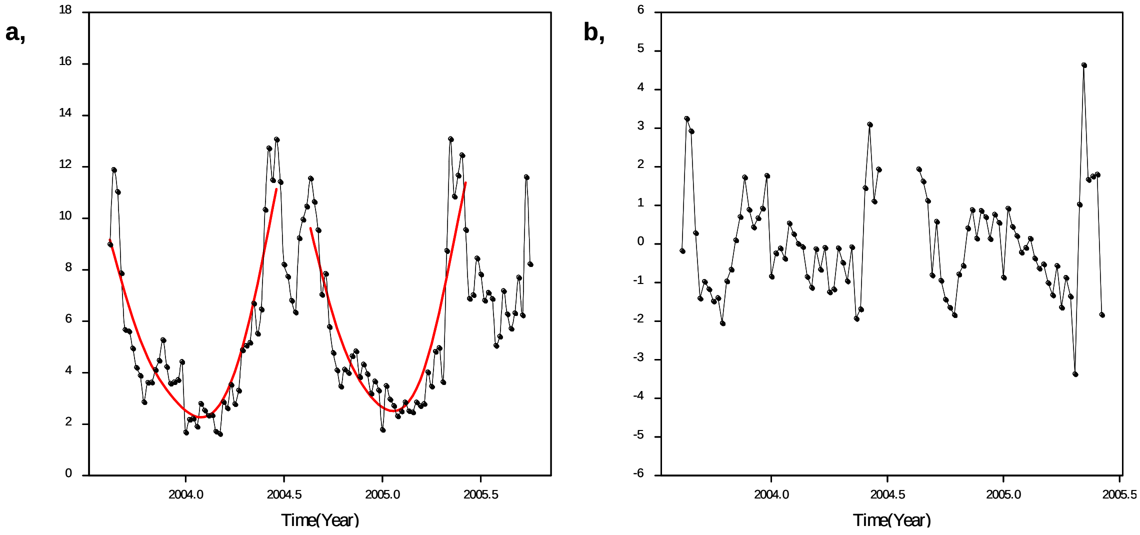

Figure 23: *Trends in yield (stems/m²) averaged across sites with fitted curves [a] and de-trended yields (stems/m²) [b]*

Environmental data was also subject to these long term seasonal fluctuations and were therefore also de-trended. A curve was fitted for air temperature which accounted for 85% of the variability in the data (figure 24a) to produce a de-trended curve for temperature (figure 24b).

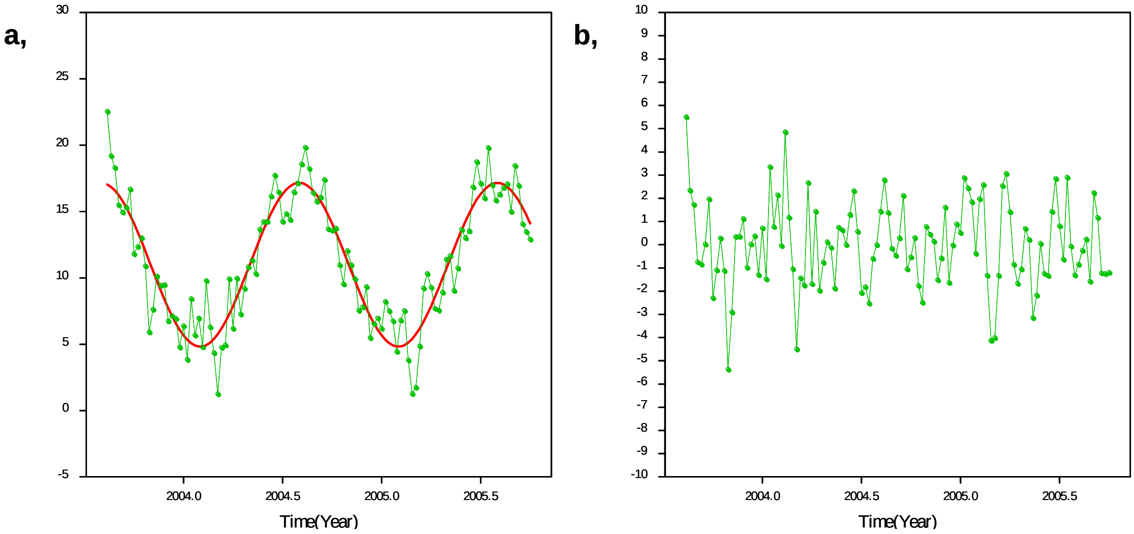

Figure 24*: Trends in air temperature (°C) averaged across sites with fitted curve [a] and de-trended curve [b]*

Light integral data (figure 25a) was also fitted to a curve in order to remove the variability of long term seasonal trends (figure 25b). The fitted curve for Radsum accounted for 91% of the variability in seasonal data.

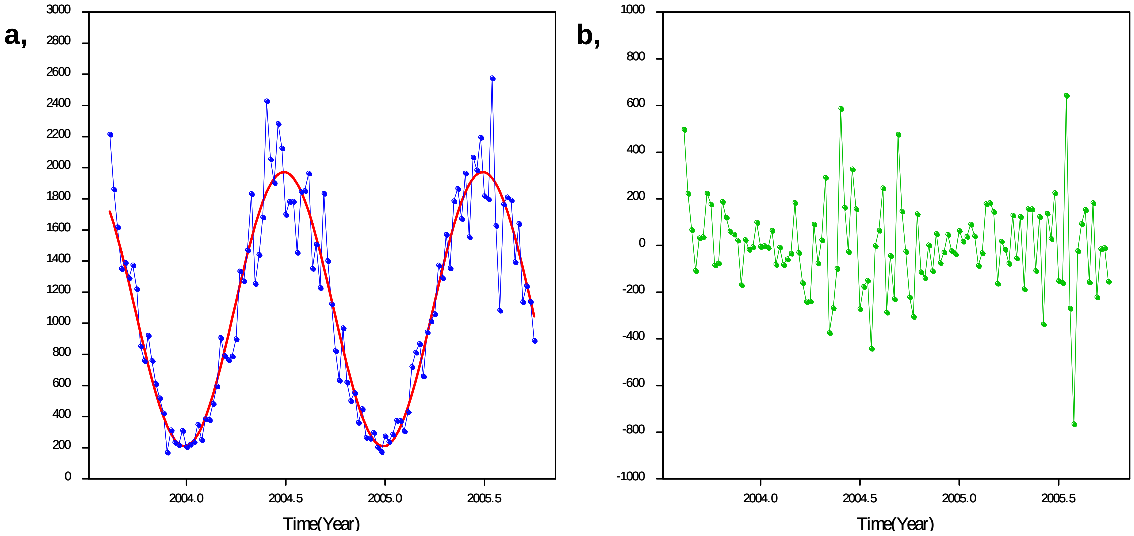

Figure 25: *Trends in radsum (J/cm² per day) averaged across sites with fitted curve [a] and de-trended curve [b]*

Having removed variability due to long term seasonal effects, relationships between yield and measured environmental parameters were investigated to determine if short term fluctuations in environment had an influence on variability in yield in the following period. Relationships were examined between current yield and environmental parameters measured in previous weeks with time lags of 1, 2, 3, 4, 5 and 6 weeks. This was achieved by plotting the two test periods for yield against environmental factors in de-trended data with straight lines fitted to each data set. None of the fitted straight lines found any statistically significant relationship between yield and air temperature at any week during the proceeding six weeks for either of the two yield test periods (figure 26).

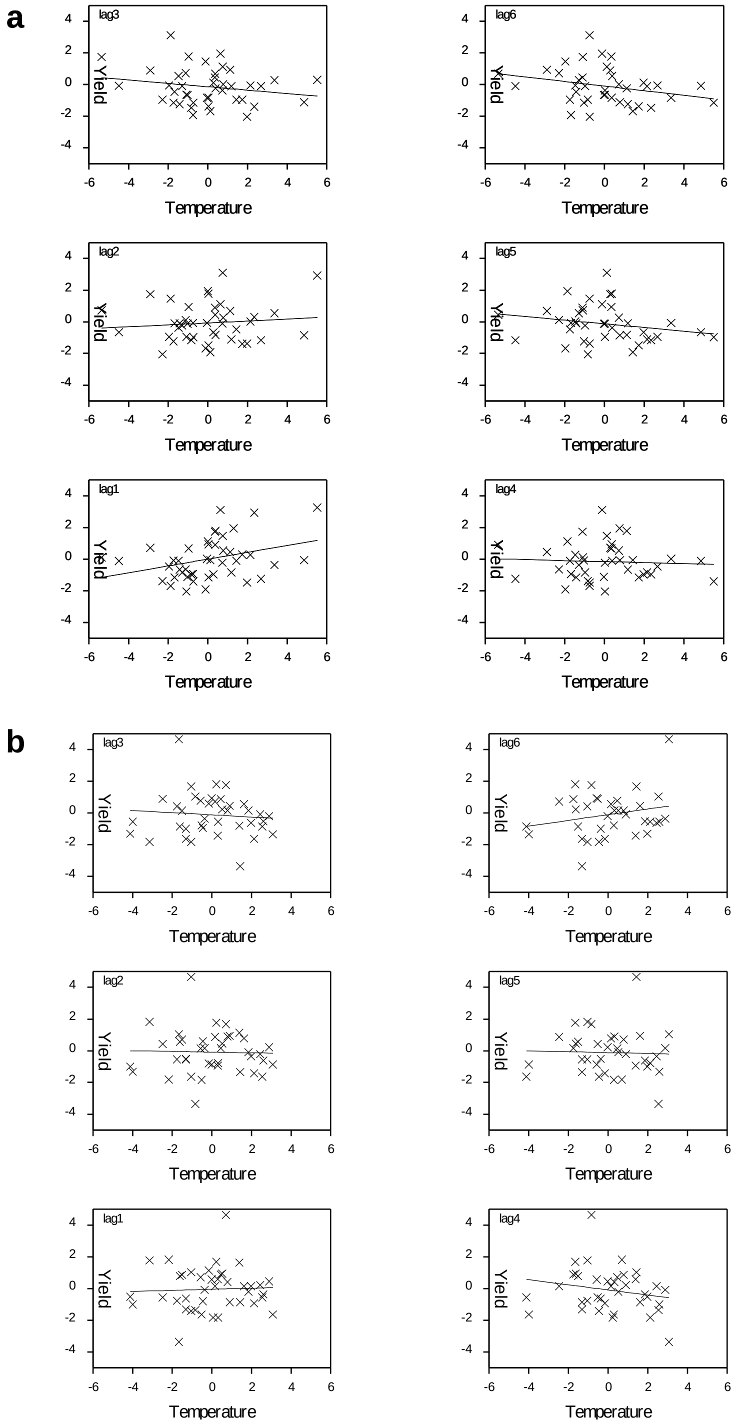

Figure 26: Relationship between yield and air temperature at lags of 1, 2, 3, 4, 5 and 6 weeks for weeks 32 in 2003 to week 24 in 2004 (a) and weeks 33 in 2004 to week 22 in 2005 (b)

Similarly, none of the fitted straight lines for de-trended yield and Radsum data suggested that there was a statistically significant relationship between yield and radsum at any week during the proceeding six weeks for either of the two yield test periods (figure 27).

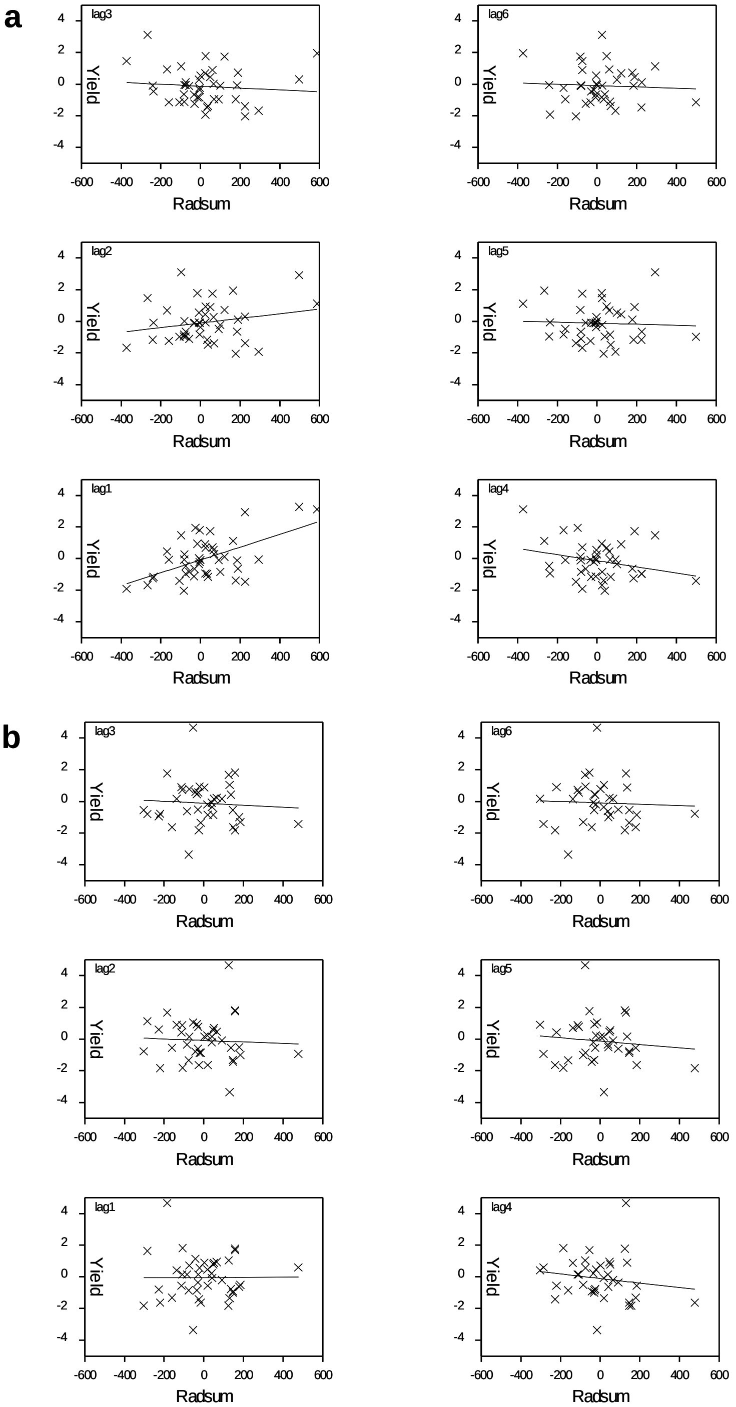

Figure 27: *Relationship between yield and radsum at lags of 1, 2, 3, 4, 5 and 6 weeks for weeks 32 in 2003 to week 24 in 2004 (a) and weeks 33 in 2004 to week 22 in 2005 (b)*

Similar analyses to the above were undertaken for a number of other environmental variables and none of these analyses showed evidence of significant relationships with yield. An analysis that allowed separate regression relationships for the cooler winter months and warmer summer months, on the basis that the effect of the environmental data may be more apparent for distant data, also failed to show evidence of significant relationships; as did an analysis using lagged data from as far back as 8 weeks.

Hence although crop growth and yield is clearly influenced by long term seasonal effects and therefore environmental conditions, the time series analyses carried out were unable to identify factors that had a shorter term impact on yield in these complicated systems.

Comparison of yield from site to site

Total yield of marketable stems across all varieties on one site was compared with the average of total yield across all six sites to examine how agronomic differences may have influenced productivity (figure 28). Interestingly, despite a wide range of locations and agronomic practises (e.g. soil cooling / supplementary lighting etc), none of the sites stand out as being very different from the rest, although differences from the 'norm' can be seen at different times of year. On site 2, for example, the spring flush (weeks 14 to 18) is greater than the average flush from the rest of the sites in both 2004 and 2005. A similar peak in productivity above the norm occurred in weeks 18 to 24 at site 5 in 2004 and 2005, however soil cooling was the norm at this site and hence the average yield data for the site largely reflects cooled beds has already been shown to benefit total yield. Unfortunately soil temperature was not logged at site 2 to evaluate if this fell below average (at a time of year when temperatures are too high) which may be expected to result in higher than average productivity noted, however as this peak was slightly earlier in the year than that observed at site 5, it may well have been the result of other differences at the site. Similarly there are gaps in other environmental data (e.g. water use, air temperature) from site 2 making it difficult to examine if trends in other environmental parameters coincided with the peaks in yield seen.

Total yield at site 3 was generally below the average yield across all sites particularly between weeks 7 and 46. It was noted previously that soil temperature was also generally higher at site 3 than the remaining sites (with temperature exceeding 16°C for nearly half of the year). It is possible that these high temperatures may have been at least part of the reason for this lower yield. Site 3 also maintained higher than average air temperatures during periods of the year where heating would be required and this does not appear to have produced benefits in terms of increased yield compared with sites running lower air temperatures.

Site 6 stands out as having more variability in yield from week to week compared with the other sites. There are however no consistent trends from year to year or any corresponding changes in the environmental data collected to suggest any particular environmental factor was responsible for this variability. Since this site was also the smallest of the participating nurseries, it seems possible that this variability is due to the smaller sample size.

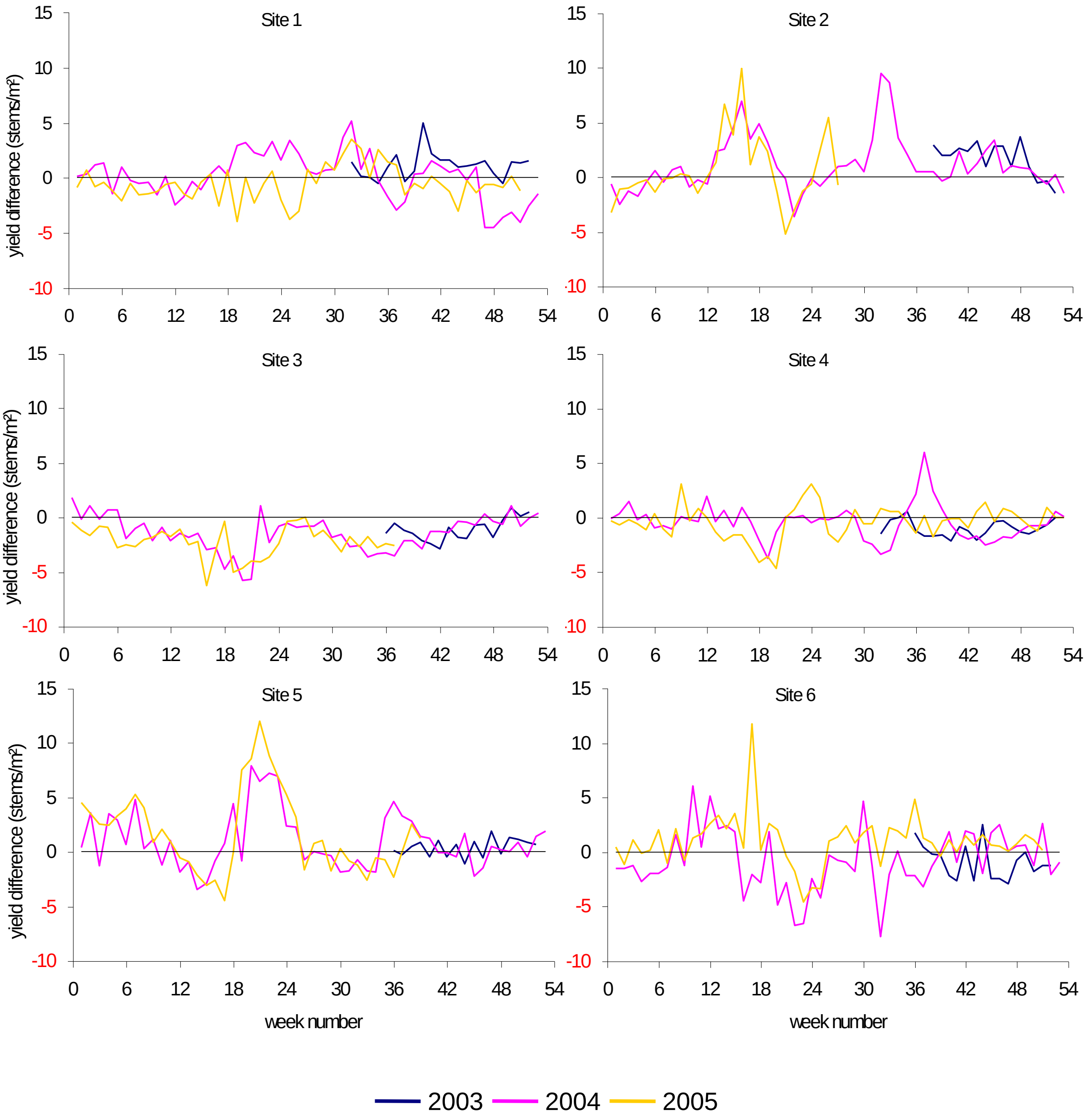

__Figure 28:__ Comparison of yield data per site with average data across all six sites

Supplementary lighting

Sites 3 and 5 used supplementary lighting at low intensity during the first winter season of the trial. The lighting was used according to normal practice for each site and there are no direct comparisons that can be made for formal statistical analyses between lit and unlit areas of the same cultivar. Differences between trends in data from winter 2003/04, when lighting was used, and 2004/05, when lighting was not used, have therefore been used to evaluate the impact of lighting.

At site 3, lighting had been used where the varieties Orange Queen and California were grown but not where Rebecca was grown, hence differences in production patterns between these varieties could be compared over the winter 03/04 and 04/05 periods. Lighting had an apparently small impact on total yield of Orange Queen which had 10 more harvestable stems/m² than Rebecca during the period of week 44 to 12 in 2003/04 (figure 29) but both varieties produced comparable numbers of stems/m² over the week 44 to week 12 period in 2004/05. California however was more similar to Rebecca than Orange Queen in both years and therefore did not apparently benefit from the use of supplementary lighting.

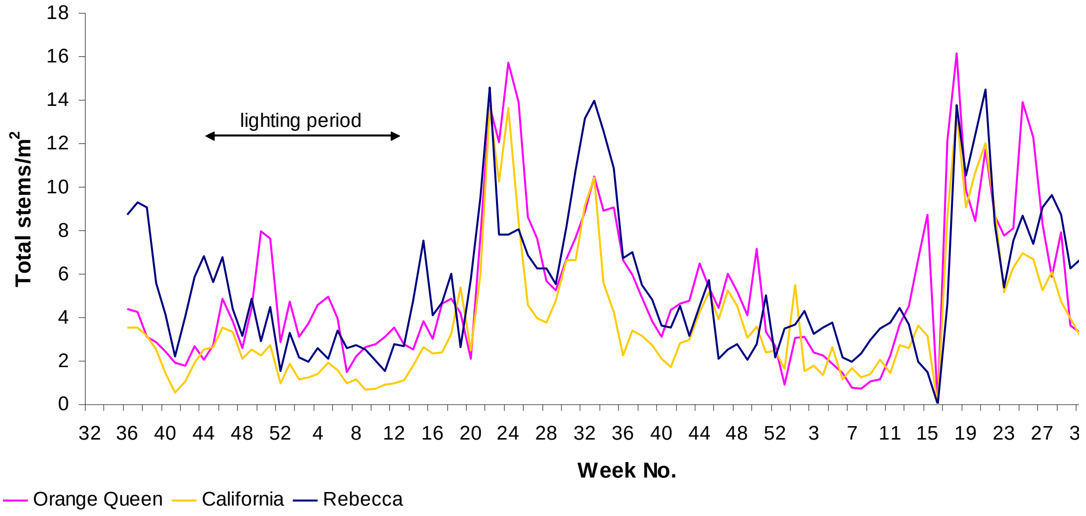

Figure 29: *Comparison of total marketable yield at site 3 with two varieties grown with supplementary lighting in 03/04 but not in 04/05, and one variety grown without supplementary lighting throughout*

Effects of lighting were apparently more marked on quality. Orange Queen had 35 to 71 % grade 1&2 stems in the lit period of 2003/04 compared with 0 to 38 % for the unlit Rebecca (figure 30). By comparison Orange Queen produced 20 to 54 % grade 1&2 stems in the winter 2004/05 period when it wasn't lit which is comparable to the 18 to 61% produced by Rebecca over the same period.

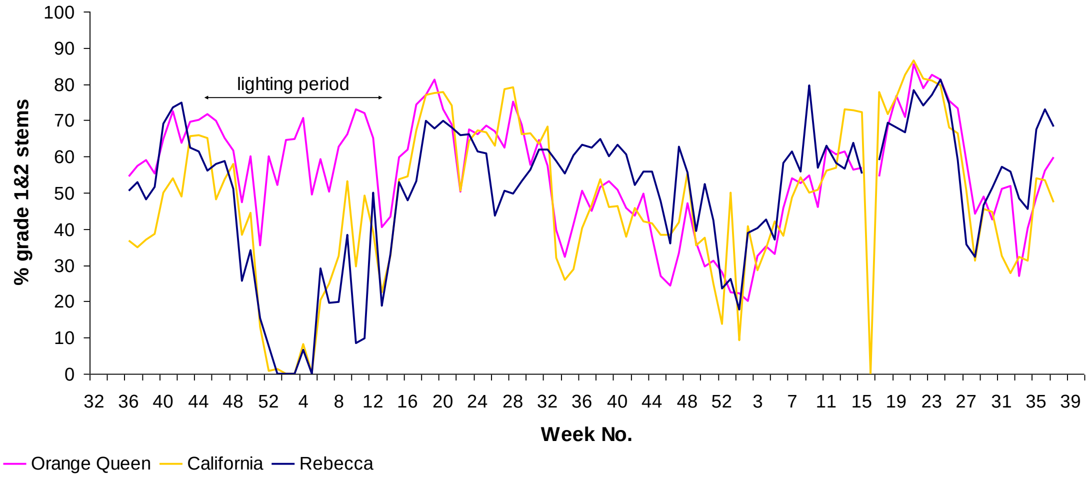

Figure 30: *Proportion of grade 1&2 stems of three varieties harvested from site 3*

Differences in the proportion of grade 1&2 stems largely translated to changes in grade 3 stems. Hence Rebecca had a greater proportion of grade 3 than 2 stems during the winter period of both years, whereas Orange Queen only had a greater proportion of grade 3 than 2 stems in the winter of 2004/05 when no lighting was used (figure 31).

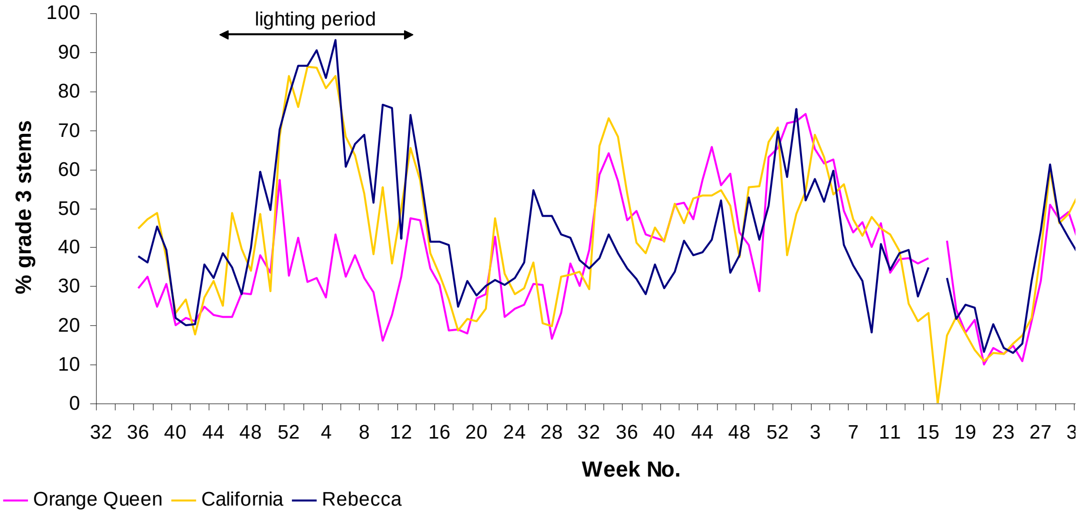

Figure 31: *Proportion of grade 3 stems of three varieties harvested from site 3*

Whilst the above data suggest Orange Queen may have benefited from supplementary lighting, California did not behave in a similar pattern suggesting that either varieties respond differently to lighting or that there were differences between the plots which masked these effects for Carolina.

Data from site 5 also conflict with the results for Orange Queen at site 3 since there were no differences in yield or grade out between 2003/04 and 2004/05 at site 5 which could suggest that there were no benefits from the use of lighting in 2003/04. This is despite the fact that site 5 also collected data for the variety Orange Queen. This suggests that either the lighting used at site 5 had less impact because of its set up (e.g. intensity too low?), or that there were other cultural factors at site 5 that limited response to lighting.

Orange Queen at site 5 for example was produced using the bed temperature regulation system whereas site 3 had unregulated soil temperature. Air temperature during the winter was also higher at site 3 than at site 5 which may help enhance the benefits of the lighting whereas the lower temperature at site 5 may have limited the photosynthetic response to the increase in light supplied.

DISCUSSION

Regulating soil temperature for the variety Irenna demonstrated that the system can be effective in lowering soil temperature in summer and raising soil temperature in winter in a UK nursery. The benefits on yield were less clear cut. Although beds benefiting from temperature regulation appeared to have a consistently higher total stem yield, this difference can not be considered to be statistically significant over the course of the whole experiment (i.e. mid 2003 to end 2005) because of the variability in the data. Significant improvements in quality were however demonstrated. The high level of variability in the data for all yield/quality related comparisons highlights the difficulties of working with data which had to be collected according to market requirements rather than to a standard stage of maturity. Whilst the approach in the current trial is a valid reflection of commercial practise, it is hard to extrapolate this for use by other growers who are likely to have a different set of constraints placed on their harvesting systems.

Soil temperature data logged on all sites suggests that site 5, which had the soil temperature regulation system installed, had the lowest ambient (i.e. unregulated) temperatures of all the sites assessed. This may have been because site 5 had soil temperature regulation as standard throughout the nursery and only the 'unregulated' bed was uncoupled from the cooling/warming system. Hence the unregulated bed may have been at a slightly lower temperature because soil in adjacent beds benefited from cooling. Given these differences, it would appear that the benefits of temperature regulation achieved at site 5 would be a conservative estimate of what other sites might expect by installing their own temperature regulation systems. Site 3 had the highest soil temperature overall and also lower yield than the remaining sites, suggesting that the use of soil cooling may be of greatest benefit to this site out of the 5 nurseries that were not using this technique.

It is also apparent that whilst soil temperature regulation systems are generally thought of as being of use for soil cooling, they also have potential for increasing soil temperature in winter which is likely to be more energy efficient than heating the air and has potential for increasing winter yield (which has potential for higher returns than increasing yield during the main periods of productivity). Hence whilst growers may question the cost effectiveness of installing a cooling system when its use may be limited to 6 to 23 weeks a year for cooling, they may achieve further benefits by using the system with heated water in the winter period and extend the usefulness of the system by around an extra 12 weeks a year (i.e. November to January).

Irrigation systems and management clearly varied from site to site in this project. Whilst it has not been possible to identify relationships between yield and environmental variables logged, some clear relationships between Evaposensor data and actual water use have been identified, even though the sites monitored had used radsum data to trigger irrigation. Whilst radsum data is more likely to be already available on nursery climate control systems and therefore more readily used to control irrigation (i.e. where irrigation is normally controlled manually) it is possible to capture a signal from an Evaposensor that will link in to an existing irrigation system, and this has already been achieved on one of the sites that participated in this project. According to the relationships found, this change may give more efficient control of water use. Initial use of such a system is likely to require a trial and error approach to identify relevant set points, but once started there is potential to manipulate settings in order to make more efficient use of water.

It has not been possible to determine any significant links between short term changes in environmental conditions and yield through time series analysis of the detailed data set collected. The high degree of variability in the data has been limiting in terms of defining significant relationships. The principle of comparing nursery yields has worked well in other sectors, e.g. the tomato recording scheme and can provide a base for constructive group discussions. However, alstroemeria production is clearly too complex for identification of key factors influencing week to week productivity by time series analysis alone. Understanding the weekly fluctuations in tomato yields has been made possible through the use of more detailed physiological experiments where produce is harvested at a defined stage and where treatments may be imposed under well controlled conditions; similar experiments may also be successful for alstroemeria. The most conclusive data from this project has arisen from comparing soil temperature regulation on one site and on one variety. In this case, although there was variation arising from positional differences of the regulated and non regulated bed within the site, factors such as timing of harvest and agronomic management style would have been common, helping to reduce variability. Another means of reducing variability within this project would have been to have two or three varieties in common across all sites, with these varieties planted at the same time on all sites. This would have provided more meaningful site to site comparisons from which differences in environmental parameters could be better examined. A further extension to this approach would be to have additional treatments on one or more sites, e.g. having two beds of the same variety given different nutrition or irrigation regimes. A more robust comparison of the effectiveness of these types of treatments could then be made.

CONCLUSIONS

Soil cooling to maintain temperature below 15°C gave a significant improvement in quality and reduced the number of stems removed for thinning.

Soil 'cooling' systems may also be used to increase soil temperature in winter and promote further benefits in productivity.

Actual water use resulting from control based on radsum settings correlated well with recoded Evapometer data indicting the potential for the use of automated irrigation controlled by Evapometers to improve the efficiency of nursery water use.

Time series analysis has been unable to identify key environmental variables responsible for short term fluctuations in alstroemeria yield despite the clear link between yield and environment in the longer term seasonal trends. Successful yield prediction is likely to require more detailed and controlled experiments. More information may have been identified from the project if there had been greater control over parameters such as varieties grown, planting dates and also harvesting standards.

TECHNOLOGY TRANSFER

Project review meetings with the participating sites were held in April & November 2004 and November 2005; the latter meeting included a briefing from Tim Pratt on environmental control systems for protected cropping. A written summary was distributed to growers in July 2005 and an article was published in HDC News in March 2006 (No. 121 p26-27).

ACKNOWLEDGEMENTS

HDC provided the funding to support this project.

Our thanks go to the six nurseries participating in the project who invested significant amounts of time in the work by separating out trial areas for detailed yield records as well as periodically retrieving environmental data for processing at FEC Services. The growers from these sites along with the project co-ordinator also invested their time in attending and contributing to the project meetings mentioned above.

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