Project Title:	Protected tomatoes: enhancing the performance of temperature integrating climate control strategies – a commercial demonstration
Project Number:	PC 188a
Project Leader:	Tim Pratt Technical Projects Manager FEC Services Ltd Stoneleigh Park Kenilworth Warwickshire CV8 2LS Tel: 024 7669 6512 Fax: 024 7669 6360
Report:	Final Report - June 2004
Previous Reports:	See reports for PC 188
Key workers:	C.W. Plackett, FEC Services Ltd Dr Tim O'Neill, ADAS Consulting Ltd
Location of Project:	FEC Services Ltd, Warwickshire Lansdale Nurseries Ltd, Lancashire
Project Co-ordinator:	Mr. P. Pearson A Pearson & Sons Ltd Alderley Edge Cheshire SK9 7UW Tel 01625 582166 Fax 01625 586976
Date Project Commenced:	1 November 2002
Date Project Completed:	28th February 2004
Key Words:	Energy efficiency, energy savings, climate control systems, edible crop production, temperature integration, humidity control, tomato

Table of Contents

Grower Summary

Science Section

Grower Summary

Headline

A temperature integration (TI) based control strategy was applied to the production of a commercial crop of classic round tomatoes and compared to a more conventional approach to temperature control over two cropping seasons in 2002 and 2003.

- Energy savings of 8.4% and 5.9% were recorded in 2002 and 2003, respectively.
- In 2002, higher CO_2 levels in the TI treatment and less chilling of the head of the crop due to reduced venting gave an extra truss per m^2 and resulted in a yield increase of 4.3%, valued at £13,900 per ha.
- In 2003, identical CO_2 levels and the avoidance of venting at low outside temperatures in both treatments meant there was no difference in yield.
- An earlier planting date, higher light levels early in the year and improved crop management all contributed to a 8.2% increase in average yield in 2003 (61.22 kg/m^2) compared to 2002 (56.57 kg/m^2).
- Humidity control followed the same principles in both treatments.
    - Always try to vent first then heat rather than the more common ‘heat then vent’ approach.
    - Limit minimum pipe temperature to a maximum of 50^oC with all influences applied.
- There was no difference in disease (*Botrytis*) levels between treatments in either year.
- Using current energy prices, the average annual energy saving over the two years of the project are worth at least £4,485/ha.

Background & Expected Deliverables

The Climate Change Levy (CCL), together with rising fuel prices and increasing pressure to reduce environmental impact, means that energy efficient production continues to be an important issue for all producers of protected crops.

Over recent years a considerable amount of R&D has been carried out on temperature integration (TI). TI takes advantage of the fact that crops will grow just as effectively when grown in an 'average' environmental temperature as they would under a single 'fixed' temperature. This principle offers significant potential for energy saving.

Energy can be saved by allowing the temperature in the greenhouse to be lowered during periods when weather conditions lead to high heating costs (e.g. during a cold, windy night). Such periods are then compensated for by allowing the greenhouse temperature to rise at times when conditions are more favourable (e.g. on a still, bright sunny day).

Most previous R&D in this area has concentrated on crop response to TI, and has shown that considerable temperature swings can be accommodated over periods of up to 14 days without loss of yield or quality. However, despite these findings, commercial uptake of TI has been minimal. Growers have been reluctant to abandon the environmental control strategies and set points they have traditionally used. Concerns over humidity control, environmentally linked disease levels and crop balance & regularity have been cited as the main obstacles to change. With these issues in mind the objectives of this work were to:

- Demonstrate the level of energy saving that can be achieved by applying TI on a commercial nursery.
- Quantify any crop related effects. (disease, yield, etc.)
- Determine the overall economic impact of TI strategies on the production of a commercial tomato crop.
- Give guidelines on the application of TI for a commercially grown crop of tomatoes.

Results obtained during the first crop (2002) delivered these objectives. However experience gained during this period meant that the full potential of TI was not realised. An extension to the project was agreed and a second crop was grown during 2003. The science section of this report relates to the 2003 crop only. For greater detail on the 2002 crop, the report for PC 188 – 'A demonstration of advanced environmental control strategies' (Pratt et al., 2003) should be read.

Summary of Project and Main Conclusions

Research method

Over two complete cropping seasons between 2002 and 2003, crops of 'Encore' classic round tomatoes were grown in two separate greenhouse compartments on a commercial nursery in the North West of England. The size of each compartment was approximately 3,600m^2. Each compartment had a separate heating circuit and hot water heat meters were installed to record energy use throughout the trial. Nursery staff kept ongoing yield and disease records and a detailed disease assessment (*Botrytis*) was carried out at the end of each season.

A Priva Integro v720 environmental control system with TI software was used. This equipment and the associated software have been commercially available for several years. One compartment was grown using the nursery's 'conventional' control strategy whilst the other was grown using the same basic set points, but with the addition of simple TI. Simple TI relies on reduced venting during periods of high solar gain to capture 'free energy'.

Results

Control strategies (2002)

During the early season (weeks 5 - 11), simply 'turning on' TI gave average energy savings of 5%. This was achieved by increasing the temperature setting at which ventilation was introduced and allowing the night temperature to be automatically reduced to compensate. These settings allowed the TI treatment to:

- Realise at a higher temperature than the conventional one when solar gain was high during the day period.
- Automatically reduce the heating temperature during the night period following a warm day, whilst maintaining the same average temperature as in the conventional treatment.

Over the period from weeks 12 - 17, the predominant energy requirement of the greenhouse became driven by the need to control humidity rather than temperature and savings reduced to almost zero despite the fact that the original TI settings were retained. To accommodate the changing requirement for energy, a radical approach to humidity control was adopted. This involved relaxing the basic humidity control strategy by not reacting to brief periods of poor humidity. This was replaced by a 'heat boost' triggered by consistently high humidity levels, typically levels >85% relative humidity for >2 hours. Whilst TI working in combination with this approach gave energy savings as high as 30%, a prolonged period of poor weather conditions revealed its limitations. *Botrytis* was noted on leaf debris in both treatments, however it was notably worse in the TI treatment. This required a clean up period where TI was turned off and a single application of the fungicide Scala was given to both treatments.

The use of TI was reinstated in week 21. The environmental control settings were refined to fully integrate the needs of TI alongside the requirements to control humidity. A successful humidity control strategy based on a ‘ventilate then heat’ approach was devised which gave consistent energy savings averaging 11%. This method of humidity control contrasted with the control treatment where the commonly used ‘heat then ventilate’ approach was retained.

As weather conditions deteriorated towards the end of the season (from week 38 onwards) a more conventional ‘heat then ventilate’ approach to humidity control was gradually introduced to avoid excessive dips in greenhouse temperature. Over this period energy savings averaged 7%.

During the last few weeks of the season (weeks 43 - 44) TI was turned off. Crop requirements and the prevailing weather conditions meant there was little venting in the conventional treatment and therefore little opportunity for energy savings with simple TI.

<u>Control strategies (2003)</u>

The crop was planted in week 50 (2002). This meant a longer period of poor weather where there was little solar gain for simple TI to take benefit of. This was compounded by the higher light levels than in the previous year and a different general growing strategy. These factors combined to require an average temperature as much as 2°C higher than expected between weeks 5 - 10 (when compared to the crop grown in 2002).

This extended the period at the beginning of the crop when simple TI was not able to deliver any savings from 5 weeks (2002) to 11 weeks.

From week 10 - 25 TI was applied in the way proven during 2002. The key control strategies used were:

- Use humidity influences to increase the ventilation temperature only when the humidity deficit exceeds what is considered to be a safe level.
- Only allow TI to reduce the heating temperature between 1 hour before sunset and 1 hour before dawn.
- Gradually increase the heating temperature to normal levels prior to dawn to ensure a warm, dry crop during the period of highest condensation risk.
- Use a minimum heating temperature of 15°C.
- Integrate over a period of 7 days.

Energy savings during this period peaked at 20% in week 13 then gradually fell as energy demand became dominated by humidity control. Savings were also reduced due to the use of the gro-pipe between weeks 14 - 22. This was introduced to speed fruit ripening and help keep balance in the crop. Between weeks 10 - 25 energy savings averaged 9%.

From week 26 - 34 the temperature control goal was to keep the average as low as possible and TI was turned off.

However a different approach to humidity control was taken in the TI treatment. This was not related to any TI principles. Both crops had shown no signs of *Botrytis* infection to this point and were considered to be well balanced. In addition, the good weather conditions meant that the crop was subject to a regular drying period during the day to help reduce the viability of any spores that may have developed. The *Botrytis* risk was therefore considered to be low. As a result the approach to humidity control was relaxed between sunset and 01:00. This represented the period of lowest risk as:

- Venting continued past sunset, helping to ensure good air movement.
- The crop was expected to be warm following bright, warm days.
- Glasshouse air temperature was falling.
- The thermal mass of the crop meant that the fruit and stem in particular were expected to be at a higher temperature than the air. Therefore reducing the risk of condensation on the crop.

In practice this meant that no minimum pipe temperature was used during this period. In the control treatment minimum pipe settings were retained which gave a maximum of 50ºC at a HD of 2.0g/m^3. Minimum pipe settings reverted to the same as in the control treatment from 01:00 onwards. This was to ensure that the crop was dry and warm prior to sunrise. By week 29 the level of energy saving (20%), humidity conditions seen in the TI treatment and crop condition gave the nursery owner and manager the confidence to apply this approach in the control treatment.

From week 35 gradually deteriorating weather conditions meant that keeping the average glasshouse temperature as low as possible was no longer the driving influence on temperature control. TI was turned on again and the increase in ventilation temperature at high HD was gradually built up (maximum ventilation temperature of 26ºC). At the same time, *Botrytis* risk was assessed to be increasing and minimum pipe settings to aid humidity control were reinstated during the sunset to 01:00 period in both treatments. Energy savings during this period averaged 16%.

By week 42 the main climate control goal was to maintain average temperatures and speed fruit ripening. Deteriorating weather conditions and no need to actively control humidity from a disease point of view meant that the ventilation temperature was increased to 24ºC all the time in the control treatment. This left little additional solar gain available to TI through reduced venting so TI was turned off. The gro-pipe was also turned on again using heat from the flue gas condenser only and delivering a 24-hour average temperature of 35ºC. The crop was pulled out in week 45.

Energy

The table below shows the total energy use for each treatment for each year.

	2002	2003	
Block	**Specific Energy Consumption (kWh/m^2)**	**Specific Energy Consumption (kWh/m^2)**	**2003 as % of 2002**
Conventional	418	473	113%
TI	383	446	116%
Difference	35 (8.4%)	27 (5.7%)	

Note that these figures relate to the heat energy delivered by the piped hot water system to each compartment. To determine the quantity of gas saved, the efficiency of the boiler and the distribution network also have to be taken into consideration. Assuming a seasonal efficiency of 80%, 43.8kWh/m^2 and 33.8kWh/m^2 of gas was saved in 2002 and 2003 respectively.

It is worth noting that the conventional treatment only used 13% more energy in 2003 compared to 2002 due to the earlier planting date. Whereas the TI treatment used 16% more. This suggests that efficiency of energy use in the conventional treatment improved in 2003 compared to 2002.

CO_2 Concentration

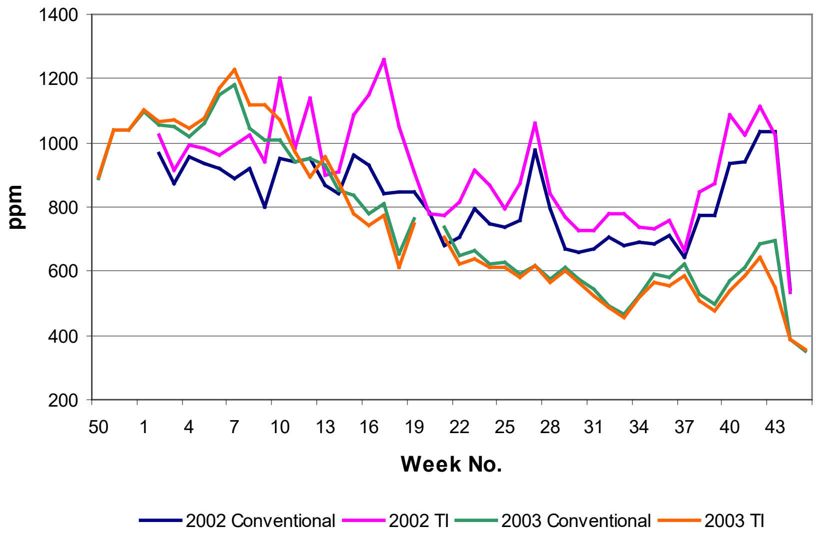
In 2002 both treatments were supplied by a common CO_2 system, with control being determined by the level in the conventional treatment. As the application of TI leads to reduce venting this led to daytime CO_2 levels that were on average 11% higher in the TI treatment. Although this could be viewed as an additional benefit of TI, it could have masked other crop effects. The CO_2 concentration also reached very high levels for brief periods that could have had a negative impact on the crop.

The CO_2 system was therefore modified for the 2003 crop so that it could be controlled independently in each treatment. Figure 1 overleaf shows the average daytime CO_2 concentration measured in each treatment.

Comparing the 2002 data, there are several points to note:

- Concentration in the TI treatment was consistently higher even when TI was turned off. This is due to an additional external wall which results in greater structural heat loss and therefore reduced venting.
- TI reduces venting further, increasing the difference during periods when TI was turned on i.e. weeks 5 - 11 and 37 – 42.
- The difference was greatest between weeks 15 - 19 when the heat boost approach to humidity control was applied in the TI treatment.

Figure 1 – Average daytime CO_2 concentration



As expected, in 2003 the CO_2 concentration in each treatment was the same throughout the cropping year. Comparing the trends of 2002 and 2003:

- Higher levels were achieved up to week 10 in 2003 due to reduced venting and higher heat demand. This was a consequence of aiming for a higher average glasshouse temperature.
- During the peak of summer in 2003 the concentration was significantly lower. This was due to the higher outside temperature and the resulting aggressive venting strategy that was used to control greenhouse temperature.

Crop Yield & Disease

The yield results from the trial were as follows:

	2002	2003
Treatment	**Yield – (kg/m^2)**	**Yield – (kg/m^2)**
Conventional	56.57	60.60
TI	59.03	61.84
Difference	2.3 (+4.3%)	1.24 (+2.0%)

Although this was not a fully replicated trial, confidence in the result for 2002 is increased as historical yield data from the nursery showed that the TI block yielded a maximum of 1% more than the control block. In addition, the difference recorded in 2002 is supported by specific factors directly connected to increased yield:

- 11% higher CO_2 level in the TI treatment.
- Less venting during cold weather, avoiding chilling the head of the crop and maintaining crop speed. The result being 2 more trusses in the TI treatment than in the control.

In 2003 the yield of the TI crop was 2% higher than the control treatment. This is only 1% higher than the historical data and as there were no other differences in each treatment that could be directly related to yield, it can be concluded that there was no significant difference in yield between the two treatments in 2003.

With regard to disease, an end of season *Botrytis* assessment was carried out by Dr Tim O'Neill in week 41 in both years. This assessed both the type of infection such as leaf scar and truss and the remaining number of viable heads. In both years there was little difference between treatments and the conclusion was that adopting the principles of TI had no effect on *Botrytis* incidence.

Conclusions

Key conclusions from this work are:

- TI can be successfully applied to a commercially produced crop of heated tomatoes. Even by applying the technique in its simplest form, energy savings in the order of 5 - 8% can be expected.
- Better CO_2 utilisation may result from using TI. This is because TI leads to less greenhouse ventilation and hence better retention of CO_2 within the greenhouse.

- TI settings need to work in harmony with other greenhouse environmental control settings. This is particularly important where humidity control is concerned. This requires a good understanding of greenhouse environmental control and the subtleties of individual climate control computers. This may require investment in training for key staff.
- When successfully applied, TI does not have a detrimental effect on crop yield or quality.
- Regular detailed crop recording (crop registration) can be a useful tool to help a grower quantify crop responses to changes in environmental management. It also serves as a long term record of crop performance to aid planning for subsequent crops.

Financial Benefits

Energy cost

The average energy saving over the two years of the project was equal to 39kWh/m^2/annum. Assuming a mains gas price of 1.0p/kWh plus climate change levy of 0.15p/kWh the saving is worth £4,485/Ha/annum.

Increased yield

Although the yield in the TI treatment during 2003 was slightly greater than that in the conventional, the differences were not considered to be significant. The yield increase recorded in 2002 was not repeated in 2003 because:

- Unlike 2002, CO_2 was controlled to the same level in both treatments in 2003.
- Unforeseen benefits resulting from the use of TI (principally the avoidance of venting when outside temperature is low) were applied to the conventional treatment in 2003.

Assuming an average net price for classic round tomatoes of £0.60/kg, the additional 2.31kg/m^2 of tomatoes produced in 2002 are worth £1.39/m^2 or £13,900/Ha.

Cost of implementation

Growers with relatively modern climate control computers may already have TI software installed. In these circumstances no additional capital investment is required to use TI and apply the recommendations from this project.

For other growers, software or hardware upgrades may be required, depending on the age and capabilities of the existing system. The costs of these upgrades will range from approximately £5,000/Ha for an upgrade to £15,000/Ha for a new system. Based on a gross benefit of £4,485/ha per annum (average energy saving), payback times of less than 1-3 years can be expected even if a complete new system is required.

It is possible to apply the principles of TI to climate control computers that do not have TI built in. However this requires increased management time to ensure that the correct conditions are maintained for the crop. Energy savings are also likely to be less. In the long term, upgrading the climate control computer will enable a grower to take full advantage of developments in climate control systems yielding improvements in energy efficiency, crop management and therefore profitability.

Action Points for Growers

Although TI was the focus of this project, many of the principles applied and lessons learnt can be used by growers in addition to 'turning TI on'.

- **Plant activation at dawn** - increased minimum pipe temperature and venting is an approach taken by some growers. Cold air entering via the vents can chill the head of the crop and have the opposite effect. Avoid venting as much as possible during this period, especially if the outside temperature is below 10ºC.
- **Minimum pipe temperature** - limit set points, including influences, to 50ºC. This will provide more than adequate air movement and system response in the event of sudden drops in glasshouse temperature.
- **Humidity control** - strive for vent then heat rather than heat then vent. Once the minimum pipe temperature is sufficient for good air movement, glasshouse temperature + 15 to 20ºC, the vents should be starting to open.
- **Controlling crop balance** - the use of day/night temperature differential should not be considered as the only available technique. Irrigation management and an increased focus on matching head density to available light should be used to a greater extent. This will allow greater flexibility in temperature control strategy and the ability to apply to changes in heating and ventilation temperatures to a greater extent.

Temperature integration – application guidelines

- **Integrating period** – 7 days was the maximum allowed by the climate control computer in this project and was applied throughout the project.
- **Heating temperature** – a minimum of 15ºC was allowed during the night time only. The daytime temperature was not allowed to be reduced by TI.
- **Ventilation temperature** – the maximum allowed was 26ºC and only when humidity conditions were favourable.

In all cases start at a low level and increase as confidence builds. Therefore start with an integrating period of 3 days, minimum heating temperature 1ºC below normal night time levels and ventilation temperature 1ºC above normal levels.

The following framework will help growers to formulate a TI based control strategy to suit their specific needs. The following simple conventional strategy has been used as the basis for the framework.

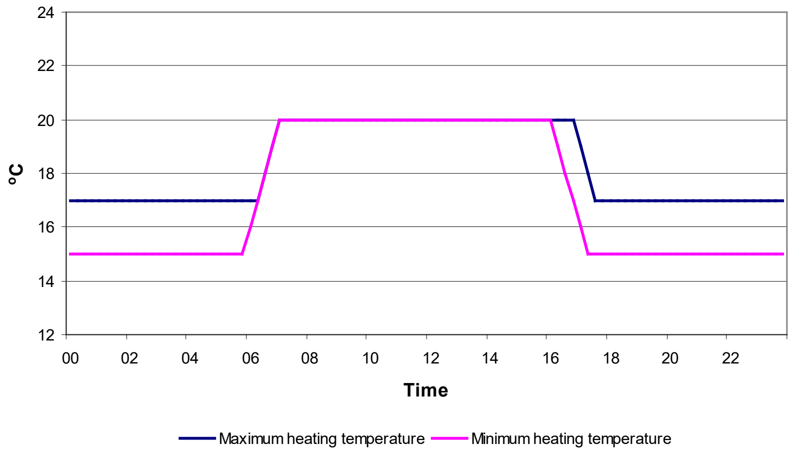
- Heating temperature – 20ºC day, 17ºC night.
- Ventilation temperature – 21ºC day, 18ºC night (heating temperature +1ºC).
- Humidity deficit target – 3.5g/m^3 day, 2.5g/m^3 night.

Heating temperature

Figure 2 below shows how the heating temperature is allowed to be varied by TI. The maximum heating temperature is the conventional approach. The minimum heating temperature is the lowest the grower is prepared to allow TI to reduce it to. TI is allowed to modify the heating temperature wherever there is a gap between the two lines. For the majority of the daytime period TI can do nothing, however as sunset approaches the temperature can be lowered as there is little light available for photosynthesis.

When solar gain during the day is high, TI will reduce the heating temperature to the minimum allowed all through the day. When conditions are marginal, the temperature will only be reduced by a small amount. During very poor weather simple TI, as applied in this project, does nothing i.e. the heating temperature reverts to the conventional approach.

Figure 2 – Heating temperature strategy



Seasonal tips

Winter - when solar gain is low the minimum heating temperature can be raised. This will spread the degree-hours in the bank over several days and give a more consistent temperature profile for the crop.

Spring – gradually reduce the minimum heating temperature as the degree-hours banked each day rise.

Summer – when the focus is keeping the average temperature as low as possible TI will save no energy so turn it off to keep things simple. However remember to turn it back on again when heating temperatures are increased towards the end of August.

Ventilation temperature

Set the ventilation temperature to track the heating temperature to give stable temperature control and responsive humidity control. A differential of 1°C is a good starting point. Also ensure that the ventilation temperature tracks the heating temperature when the latter is reduced by TI. This is achieved in different ways depending on the climate control computer in use.

Humidity control, using influences to reduce the ventilation temperature further, can be used as normal. If humidity control is normally achieved using minimum vent, this will carry on as normal.

The ventilation temperature should only be increased when the humidity conditions are above the level required, whether that is for disease control or plant growth. The table below shows a typical set of influences that could be applied during the day.

Humidity deficit g/m^3	**Influence on ventilation temperature °C**	**Resulting ventilation temperature °C**
5.0	+5.0	26
4.0	0	21
3.0	-0.5	20.5
2.8	-1.0	20.0

Take care not to apply a large influence over a small HD range, especially the positive one. This can result in a rapidly changing ventilation temperature and unstable control. Although the target HD during the day is 3.5 the ventilation temperature is not increased until it reaches 4.0g/m^3 to give a safety margin.

The next table shows the influences that can be applied during the night and the resulting ventilation temperature assuming that TI has reduced the heating temperature to the minimum allowed (15°C).

Humidity deficit g/m^3	**Influence on ventilation temperature °C**	**Resulting ventilation temperature °C**
3.5	2.0	18
2.5	0	16
2.3	-0.5	15.5
2.0	-1.0	15.0

Seasonal tips

Spring – occasional warm, bright days can cause excessively high temperatures in the glasshouse when the ventilation temperature is at it's maximum. Rather than reduce the maximum allowed and miss out on free degree-hours on an average day, look at how the vents can be made to open more rapidly on the climate control computer in use. For example on the computer used in this project it was possible to increase and decrease responsiveness according to the outside temperature.

Summer – as weather conditions improve it will not be possible use all the degree-hours accumulated during the day. Therefore the humidity influence used to increase the ventilation temperature will have to be gradually reduced, eventually to zero.

Late summer / autumn – the spring to summer transition in reverse.

Science Section

Introduction

Background

The scientific background and overview of previous work carried out in this area was fully covered in the PC 188 report for 2002 (Pratt et al., 2003). This report therefore relates primarily to the 2003 cropping season.

Extending the duration of the project to include a second cropping season was required to extend the evaluation of temperature integration (TI) by taking into account the knowledge gained during the first year of the work. It was also seen that a second consecutive year of results would further increase grower's confidence in the results achieved.

Specific areas identified as a target for improvement were:

- Humidity control - even though no difference in disease levels (*Botrytis*) were recorded at the end of the 2002 season, there were occasions when humidity control in the TI block was considered to be commercially unacceptable.
- CO_2 supply - both glasshouse blocks were supplied by a single system in 2002. As TI naturally uses less venting, higher CO_2 levels were achieved in the TI block. As a result higher yields were also recorded. Although this can be viewed as an additional benefit of TI, it could also have masked other crop related effects.
- Crop management (steering) - although this technique is widely practiced by commercial growers, there was no specific support given in this area. Subsequent analysis of the 2002 crop registration data identified areas where improved management (to both the control and TI crops) had the potential to improve marketable yield.

Main differences compared to 2002

Humidity control

In 2002, between weeks 17 - 22, a heat boost approach to humidity control was adopted in the TI block. This was implemented using a bespoke piece of software linked to the site's Priva climate control computer. Short periods of high RH (>85% for 2 hours or more) were accepted and, following their occurrence, heat boosts were applied. These delivered a drying effect which halted the development of disease spores. This approach was used because it had been shown to be effective in preventing the development of *Botrytis* in cyclamen (O'Neill et al., 2002).

Using this approach helped to accumulate more degree-hours and therefore increased energy savings. However the speed of response of the heating system, albeit acceptable for temperature control, was not fast enough to deliver a rapid reduction in humidity deficit and adequate drying effect. As a result *Botrytis* development was not halted as intended and there was an occurrence of significant *Botrytis* infection on leaf debris. This was worse in the TI treatment. A single application of fungicide was given to both treatments as a precautionary measure.

It was therefore considered that this strategy had little commercial value and a more conventional approach to humidity control (where the target HD in both treatments was the same) was applied throughout the 2003 season.

CO_2 supply

A common CO_2 system supplied both treatments in 2002. The CO_2 level used to control the CO_2 system was that measured in the conventional treatment.

Compared to the conventional treatment, the block where TI was applied was inherently 'colder' as it had an additional external wall. As a result there was a tendency to ventilate less in this treatment even when it was operated with identical set points. As a result the CO_2 level was typically 7% higher.

Adding the effect of TI, which reduces venting even further, gave a long term average daytime CO_2 level of 924ppm in the TI treatment compared to 829ppm for the conventional (11% higher).

To eliminate this difference in 2003, the CO_2 system was modified to allow the independent control of CO_2 concentration in each treatment.

Crop management (steering)

To ensure the best possible crop performance from both treatments and to help apply the lessons learnt from analysis of the 2002 crop registration data, Nic van Roosmalen, (Substratus bv) and Andy Lee (Grodan) visited the site at selected intervals throughout the season. Their task was to ensure that crop management and steering techniques commonly used by growers were successfully applied by the host grower.

Objectives

The objectives of the project remained identical to those in 2002 and were as follows:

- To demonstrate the level of energy saving that can be achieved by applying the principles of temperature integration on a commercial nursery.
- To quantify any crop related effects (particularly disease and yield).
- To determine the overall economic impact of temperature integration strategies on the production of tomatoes.

Research Method

Overview of location, facilities and cropping

As in 2002 the project was carried out at Lansdale Nurseries Ltd in the north west of England using equipment and technology widely available to any grower.

1.1.1 Glasshouse facilities

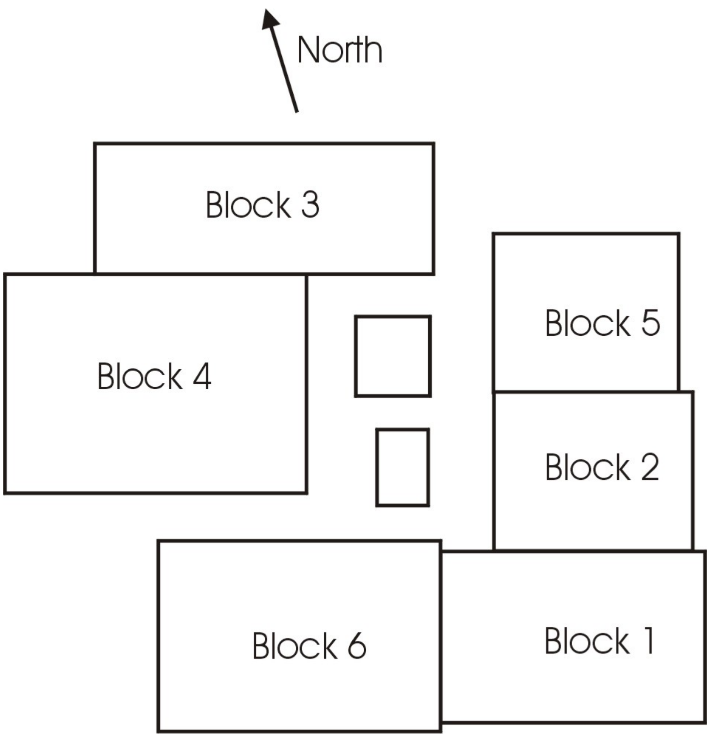
A plan view of the nursery is shown in Figure 3 below. To obtain the best possible comparison, blocks 2 & 5 were chosen for the project. Both are of a modern Venlo construction with 4.0m gutter height and 4.5m bays. Each block had independent heating and ventilation controls. Modifications to the CO_2 enrichment system also allowed independent control of the CO_2 level in 2003.

As in 2002 conventional control settings were applied to block 2 which had a total area of 3,937m^2. TI was applied to block 5 which had an area of 3,472m^2. All the results are presented on a per m^2 basis to eliminate this difference.

Switching the treatments between blocks (and reversing those used in 2002) was considered as it would have been statistically preferable. However this was not carried out because of practical constraints relating to control of the CO_2 enrichment system.

The whole nursery was controlled by a Priva Integro version 720 climate control computer which had TI software included as standard.

Figure 3 – Site plan



1.1.2 Cropping

The crop grown in both compartments was the classic round variety Encore. Young plants were brought in from a plant raiser towards the end of week 50 and planted into rockwool blocks during week 3. The crop was grown on the floor.

Data collection

All the glasshouse environmental and energy data was recorded by the Priva computer. Information was downloaded via modem connection by FEC at weekly intervals throughout the project.

Glasshouse data collected and analysed included:

- Set points - heating & ventilation temperature.
- Heating system - measured heating pipe temperature.
- Ventilation system - measured vent position.
- Glasshouse environment - temperature, humidity deficit, CO_2 concentration.
- Energy use - hot water heat meters were installed in each heating circuit to provide accurate kWh consumption information.

Crop data collected

Site staff carried out weekly crop recording including:

- Crop registration data.
- Yield, recorded daily as the fruit was picked.
- Disease incidence, primarily plant death and removal due to *Botrytis* infection.

A mid season site visit followed by a detailed end-of-season assessment of *Botrytis* infection was carried out by Dr Tim O'Neill of ADAS Consulting Ltd.

Results & discussion

As a commercial demonstration project, the overriding objective was to ensure that a successful crop was grown. Therefore great care was taken to modify the TI control strategy to take account of crop status, disease pressure, etc.

As a rule, the basic heating temperature settings applied in the conventional block were also applied in the TI block. TI was then superimposed on top of these basic settings. In order to achieve satisfactory environmental control, minimum pipe and ventilation temperature settings tended to be different in the TI block compared to the conventional treatment. This was primarily done in order to deliver the same degree of humidity control.

The following sections summarise the fundamental approaches taken as the project progressed.

Basic approach to TI

1.1.3 Heating temperature

This can be split into 4 parts within a 24-hour period:

1. Pre-dawn.
2. Day.
3. Pre-night.
4. Night.

Pre-dawn

One hour before sunrise TI was turned off and the heating temperature slowly increased to the same level as that in the conventional treatment. This was to ensure the crop was warm and dry prior to sunrise thereby reducing the risk of condensation on the fruit due to rapid temperature rise from solar gain.

Day

The heating temperature during the day time period was kept at the same level in both treatments. This was to ensure that the crop in the TI treatment was always warm and active and able to fully utilise any available radiation.

If a pre-night was not used, and there were plenty of spare degree-hours, the heating temperature was allowed to be reduced by a maximum of 1ºC up to 1 hour before sunset. This was achieved by using the TI control software.

Pre-night

Whenever a pre-night period was used, this was applied exactly the same in both treatments.

Night

This is where TI was allowed to have the maximum potential impact. Regardless of the heating temperature in the conventional treatment, TI was set to allow the heating temperature to be reduced to a minimum of 15^{o}C whenever there were sufficient accumulated degree-hours.

1.1.4 Integrating period

An integrating period of 7 days was used throughout 2003. This was the same as was used in 2002.

1.1.5 Ventilation temperature

The basic ventilation temperature strategy was set exactly the same as in the conventional treatment. The difference was in the humidity influences applied.

Humidity influences were applied such that the ventilation temperature was increased to a maximum of 26^{o}C whenever the HD was considered to be safe. This typically meant a HD greater than 4.0g/m^{3}during the day and HD greater than 3.0g/m^{3}at night. The net effect was that venting in the TI treatment only occurred:

- When the HD was considered to be too low.
- When the measured air temperature exceeded 26^{o}C.

The maximum ventilation temperature was gradually reduced as weather conditions improved and it was not possible for TI to utilise all of the accumulated degree-hours. This change was made to ensure that a suitable average temperature was achieved.

Climate control diary

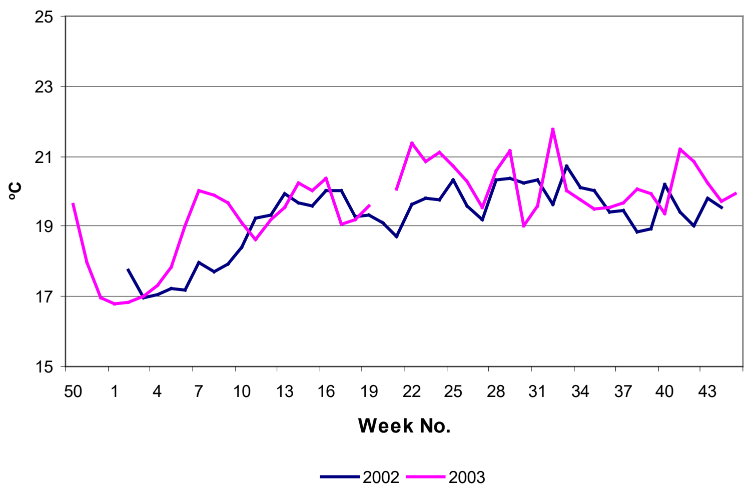
1.1.6 Week 50 (2002) to week 9 (2003)

Simple TI relies on solar gain to raise the glasshouse temperature above the heating temperature. Furthermore, unless the control treatment is venting to control temperature, there will be no additional degree-hours available to accumulate and therefore use in the TI treatment.

During this period, in addition to poor weather conditions, the crop in both treatments was considered to be too strong. This required higher temperatures to keep it balanced. Daytime heating temperatures as high as 23^{o}C in conjunction with a ventilation temperature of 24°C were therefore used throughout this period. This left little room for TI to operate bearing in mind the maximum ventilation temperature of 26°C.

This is reflected in the rising average weekly temperature over this period as shown in Figure 4.

Figure 4 – Average glasshouse temperature 2002/2003



1.1.7 Week 10 to week 13

By week 10 the crop was considered to be well balanced. This was further helped by the increasing fruit load on the crop. In the control treatment the heating temperature was reduced to around 20 – 21°C during the day and 17°C during the night. The ventilation temperature was kept within 1°C of the heating temperature and reduced by 1°C at low HD levels. In addition ventilation temperature was increased by 3°C using a HD influence over the range 3.0 – 4.5g/m^3. This took the ventilation temperature to a maximum of 24°C.

The TI treatment followed the same basic settings but allowed the night time temperature to be reduced to 15°C until 1 hour before sunrise. HD influences on ventilation temperature allowed it to be increased to a maximum of 26°C over the range 3.0 – 4.5g/m^3.

1.1.8 Week 14 to week 25

Settings were reviewed in week 14 to reduce venting around sunrise at times when outside temperatures remained low. The reason for these changes was to reduce the amount of cold air dropping onto the head of the crop and potentially chilling it. This was identified as a potential cause of poor flowering speed during the same period in 2002.

At the same time fruit load on the crop was rapidly increasing to the point that it could weaken the plant too much. The most reliable and effective method available to address this issue was to turn the gro-pipe on for a short period. This is a 25mm diameter heating pipe located within the crop at around truss height. The radiant heat from which helps to increase fruit temperature and therefore speed of ripening.

The gro-pipe was not used in 2002 (or until this point in 2003) for a number of reasons. Firstly gro-pipes are not a common feature on all nurseries and their use was therefore viewed as not being commercially representative. In addition the heat delivered by the gro-pipes was not metered, thereby making the monitoring of energy inputs more difficult.

Heat supply to the gro-pipe was mainly from the back of boiler condensing unit, topped up via a mixing valve from the main heating circuit if necessary. The gro-pipe was set at a constant 50ºC from week 14 - 18. This was followed by approximately 40ºC during the daytime only, dependant on heat recovered by the flue gas condenser, until week 22. From week 23 onwards, the gro-pipe was turned off.

Because of the status of the crop, and the fact that gro-pipes were used in both treatments, it was decided that they should be used. Energy inputs from the gro-pipes were accounted for by carrying out an analysis of pipe and internal greenhouse temperatures.

Minimum pipe

This was restricted to a maximum of 50ºC including HD influences in both treatments. This was considered to deliver sufficient heat and air movement in the bottom of the crop where there is the greatest risk of disease.

Ventilation temperature

Cyclical venting, where the vents can go from 0% to 20% and back to 0% again in less than 30 minutes, can be common. This can especially be a problem at times of the year when outside temperatures are low and radiation levels can be highly variable. This compounds the cold shock effect on the head of the plant. A steady trickle of air through vents open less than 5% will normally prove to be adequate.

This was achieved by varying the ventilation P-band according to outside temperature and by increasing the wind-lee side lag to 4ºC. The latter was gradually reduced as weather conditions improved and high glasshouse temperatures occurred. A wind influence was also applied so that in warm, still conditions the lag was only 1ºC.

P-band settings were changed from a simple 3ºC with no influences to a range of 10ºC to 2ºC over an outside temperature range of 8 to 16ºC. This means with an outside temperature of 8ºC the greenhouse temperature would have to be 10ºC above the ventilation temperature for the vents to be fully open. Alternatively if it was 1ºC above, the vents would only be 10% open. The immediate reaction of many growers to this would be disapproving. However, at an outside temperature of 8ºC very little ventilation is required to control greenhouse temperature and excessively high internal temperatures should not occur. High greenhouse temperatures will only occur at high outside temperatures (usually driven by high radiation) and the response of the settings will be to reduce the P-band to 2ºC at an outside temperature of 16ºC. This will ensure that the vents are fully open once the glasshouse temperature is 2ºC above the ventilation temperature.

By applying weather influences to the P-band the settings automatically took account of improving weather conditions through this period. This allowed a more active environment to be created as outside temperatures increased and the risk of cold shock on the head of the crop reduced.

1.1.9 Week 26 to week 34

By the end of the previous period, glasshouse temperatures had risen to the point that the overriding environmental control issue was keeping the daytime temperature and 24 hour average temperature as low as possible. Using an elevated ventilation temperature to accumulate degree-hours in the TI treatment was therefore unnecessary and potentially counterproductive. TI was turned off for the whole of this period.

However a different approach to humidity control was taken in the TI treatment. This was not related to any TI principles. Both crops had shown no signs of *Botrytis* infection to this point and were considered to be well balanced. In addition, the good weather conditions meant that the crop was subject to a regular drying period during the day to reduce the viability of any spores that may have developed. Therefore the approach to humidity control was relaxed between sunset and 01:00. This represented the period of lowest risk as:

- Venting continued past sunset, helping to ensure good air movement
- The crop was expected to be warm following bright, warm days.
- Glasshouse air temperature is falling.
- The thermal mass of the crop meant that the fruit and stem in particular were expected to be at a higher temperature than the air. Therefore reducing the risk of condensation on the crop.

In the TI treatment the minimum pipe temperature was reduced to 20ºC during this period. This was low enough for the circulation pumps to turn off. In the control treatment minimum pipe settings were retained which delivered a maximum of 50ºC at a HD of $2.0 g/m^3$.

Minimum pipe settings reverted to the same as in the control treatment from 01:00 onwards. This was to ensure that the crop was dry and the HD acceptable prior to sunrise.

Figures 5 and 6 overleaf show a typical day in each treatment. In addition to humidity influences, the calculated minimum pipe temperature also had a radiation influence to reduce it by 10°C over the range 300-500W/m^2. This effect can be seen between the hours of 17:00 and 20:00 as the calculated minimum pipe temperature rises slightly even though the HD is still above 4.0g/m^3. The difference appears at around 21:00 when the calculated minimum pipe temperature in the control treatment rises further as the HD falls, whereas in the TI treatment, it reduces to 20°C until 01:00. Comparing the HD in both cases, it falls more rapidly and to a slightly lower level in the TI treatment but recovers quickly once the minimum pipe temperatures increases at 01:00. During this period air movement was considered to be adequate due to the constant need for venting. On this particular day there was a period of around 1 hour when no venting occurred in the TI treatment. Although no detrimental effect was observed on the crop, an improvement to the approach taken would have been to apply a minimum vent setting to ensure good air movement all the time.

Figure 5 – Control treatment. standard HD control

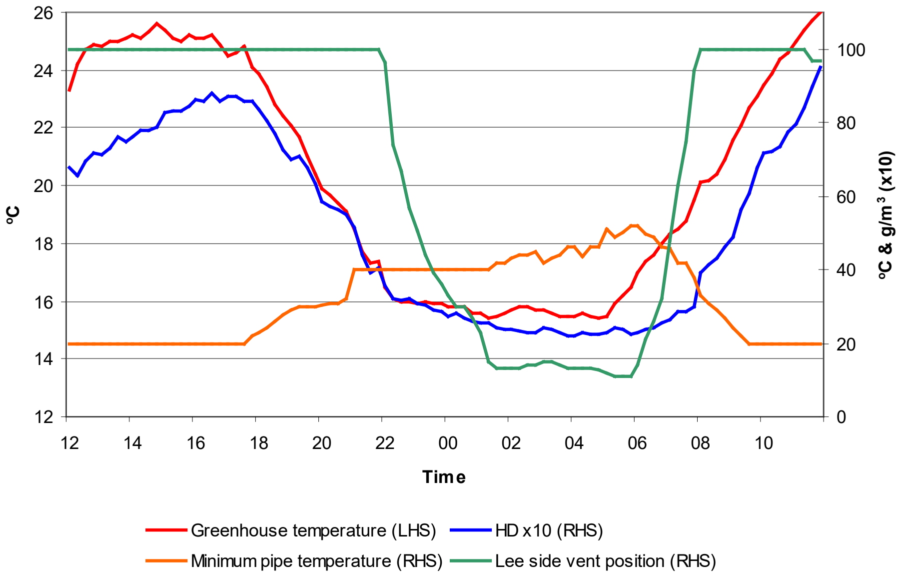
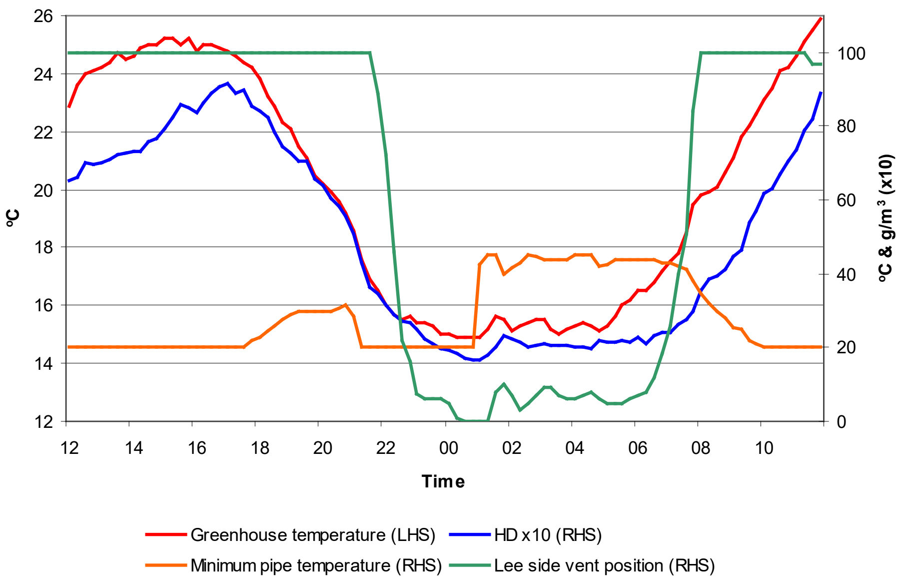


Figure 6 – TI treatment, modified HD control



By week 29 the energy saving, humidity conditions seen in the TI treatment and crop condition gave the nursery owner and manager the confidence to apply this approach in the control treatment.

1.1.10 Week 35 to week 41

Gradually deteriorating weather conditions meant that keeping the average glasshouse temperature as low as possible was no longer the driving influence on temperature control.

TI was turned on again and the increase in ventilation temperature at high HD levels was gradually built up to a maximum temperature of 26ºC. Care was taken to ensure that the average glasshouse temperatures were the same in both treatments. At the same time, *Botrytis* risk was assessed to be increasing due to:

- The crop being older with an increasing number of spent trusses dying back to the stem.
- Less reliable day time drying effect.
- Decreasing day length, therefore more prolonged periods of low HD levels between sunset and 01:00.

Therefore minimum pipe settings to aid humidity control were reinstated during the sunset to 01:00 period in both treatments.

1.1.11 Week 42 to week 45

By week 42 the main climate control goal was to maintain average temperatures and speed fruit ripening. Deteriorating weather conditions and no need to actively control humidity from a disease point of view, meant that the ventilation temperature was increased to 24ºC all the time in the control treatment. This left little additional solar gain available to TI through reduced venting. As a result TI was turned off. The gro-pipe was also turned on but was restricted to only use heat from the flue gas condenser. This delivered a 24-hour average pipe temperature of 35ºC.

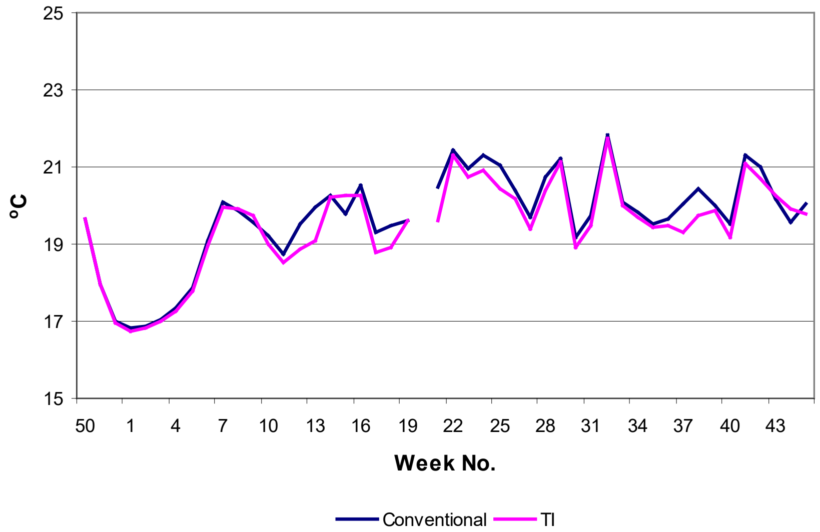
The crop was pulled out during week 45.

Environmental and energy data

1.1.12 Temperature

Figure 7 overleaf shows the average temperature in each treatment for the crop throughout the 2003 season. The goal was to keep the average temperature in both treatments within 0.5ºC of each other. This was achieved for the majority of the project. Differences of 1ºC were recorded on occasion when rapidly varying weather conditions meant that the average temperature in the control treatment was difficult to predict. Over the life of the crop the average temperature in the control treatment was 19.7ºC compared to 19.5ºC in the TI treatment. ***Note – the missing data in week 21 was due to computer failure on the trial site, this applies to all the environmental data.***

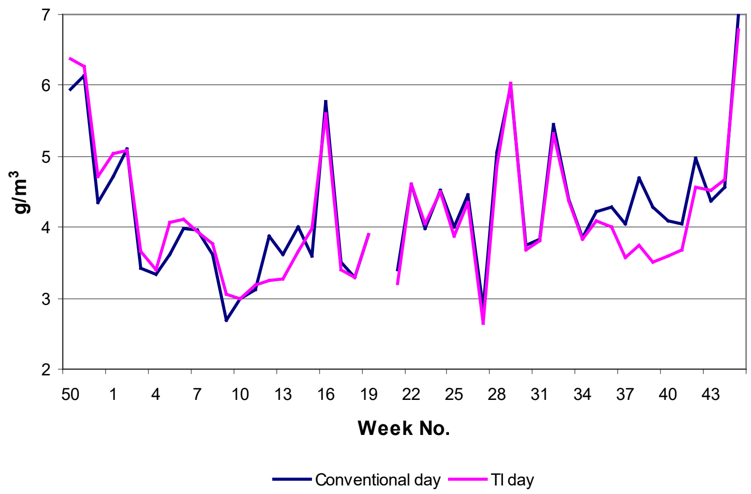
Figure 7 – Average weekly temperatures 2003



1.1.13 Humidity

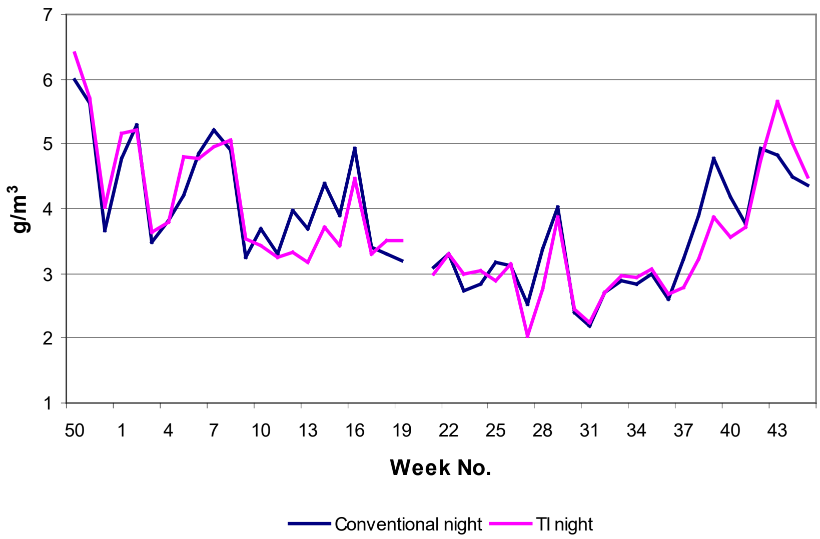
An inherent effect in applying the principles of TI is reduced venting during the daytime. This would be expected to result in lower daytime HD. This is most notable between weeks 11 - 15 and between weeks 36 - 40. These coincide with periods when TI was operating to its full extent and the greatest energy savings were made.

Figure 8 – Average day time humidity



TI was allowed to reduce the heating temperature during the night time. As a result of the reduced heat requirement during this period a lower HD would be expected. As for the daytime HD, this coincides with the periods of greatest energy saving.

Figure 9 – Average night-time humidity

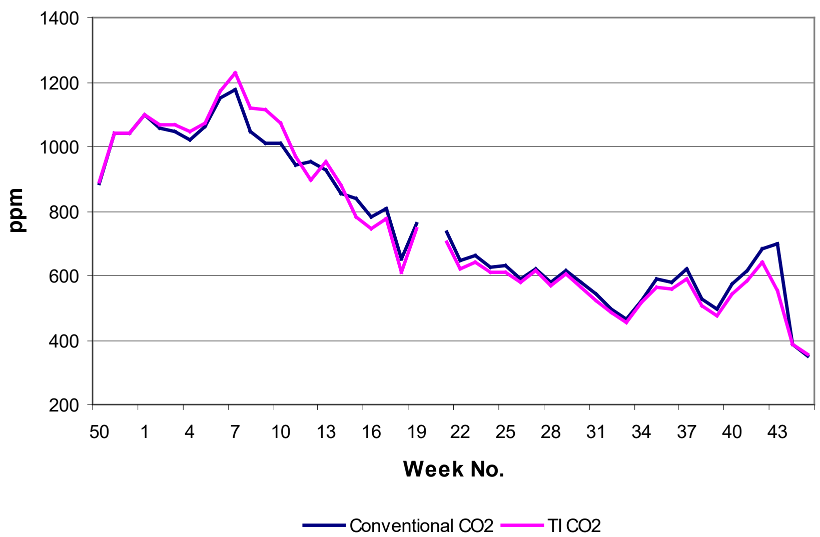


A second useful point to note is the average night-time HD during weeks 26 - 28. This was when humidity control was relaxed in the TI treatment only and the resulting average HD achieved is almost identical. This approach was applied in both treatments from weeks 29 – 34. Figures 5 & 6 show typical days from the two treatments whilst this was applied.

1.1.14 Carbon dioxide levels

The CO_2 system was modified prior to the 2003 crop to enable individual control of CO_2 concentration in each treatment. In practice, it was not possible to have a truly independent CO_2 supply. The result was that the CO_2 level was 10% higher in the TI treatment for 2 weeks whilst the control system was correctly configured. Apart from this period CO_2 levels were almost identical.

Figure 10 – Average daytime CO_2



1.1.15 Energy use

Figure 11 overleaf shows energy use in the TI block expressed as a percentage of the conventional block. All data has been adjusted to allow for the difference in size of each block and corrected for the different heat loss characteristics. Figures below 100% indicate the TI block using less energy than the conventional block.

Once TI was turned on (week 10) savings varying between 7 – 20% were consistently achieved, averaging around 10% up to week 22. There is a step reduction in energy savings in week 14 due to the use of the gro-pipe at a fixed temperature in both treatments. This limited the ability of TI to save energy. The higher energy use in week 18 was the result of incorrect minimum pipe settings being applied.

A step reduction in savings occurred in week 23. Closer inspection of the weather data (Figure 12) shows a significant increase in outside temperature at the same time. The effect being to reduce the heat demand for temperature control to such an extent that TI had little effect.

Week 26 is when humidity control was relaxed in the TI block. This delivered energy savings of up to 25%. However by week 30 the same approach had been applied to both treatments and no savings were made.

There were apparent savings during weeks 31 - 34. However this was due to a faulty measuring box that remained unnoticed for some time. The effect was reduced because control was based on the average of four measuring boxes. However this also served to hide this fault and prolong its effect.

TI was turned on again in week 35 and energy savings in excess of 20% were made for several weeks. This was aided by the fact that the average temperature achieved in the TI block was 0.5°C less than the control. Savings of 10% during this period are expected to be more realistic. By week 42 deteriorating weather conditions and no need to control humidity during the last few weeks of production meant that simple TI was unable to deliver any energy savings.

At the end of the season, total energy use in the TI block was 446 kWh/m^2 compared to 473 kWh/m^2 in the conventional block. This represents a saving of 5.9%. These figures are slightly distorted due to the periods when incorrect settings were applied or due to faulty measuring boxes. Relaxing humidity control in the TI block only, during weeks 26 - 29, also distorted the energy savings due to TI alone. Correcting the energy use data in the TI treatment to account for these periods, increases the total energy use to 450kWh/m^2 and reduces the savings to 4.9%.

Figure 11 – Comparison of energy use

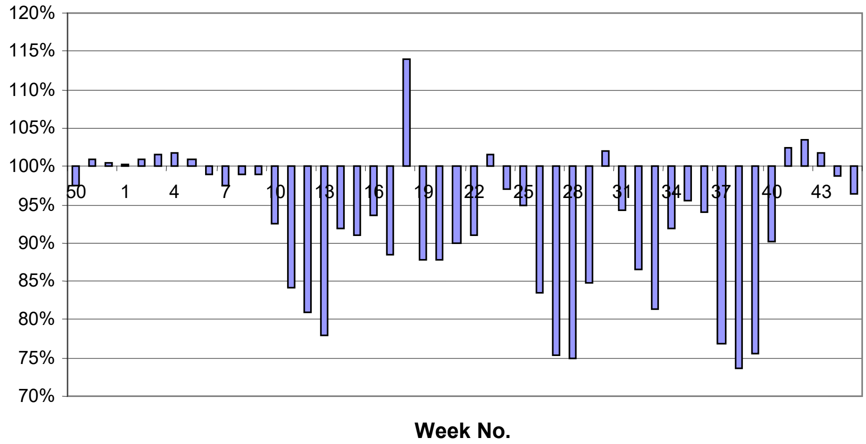
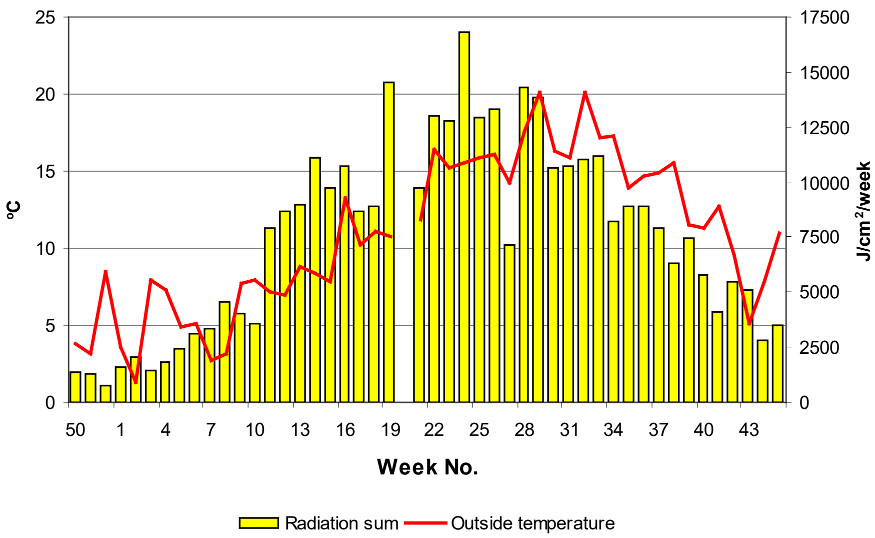


Figure 12 – Weather conditions



Crop data

1.1.16 Management

Crop management was the responsibility of Nic van Roosmalen (Substratus b.v.) and Andy Lee (Grodan) with whom the grower worked to manage the crop. Full details of the strategy used to optimise crop performance and the decisions taken throughout the growing season are given in the report attached as Appendix 3.

1.1.17 Disease

The following is the summary from the report produced by Dr Tim O'Neill resulting from the *Botrytis* assessments carried out during 2003. A complete version of the report is given in Appendix 2.

Around 2000 stems in each of two adjacent compartments of tomato, cv. Encore, where one crop was being grown according to standard heating practice and the other was grown using temperature integration, were monitored for stem *Botrytis* from weeks 17 - 43. No fungicides were applied for *Botrytis* control. The occurrence of stem *Botrytis* was low, probably due in part to the exceptionally warm, sunny weather this year and to removal of old fruit trusses from stems during the season. On 6 October 2003, the mean number of *Botrytis* stem lesions was less than one per 100 stems in both crops. At all assessments of the mean number of surviving, non-wilting heads, there were no statistically significant differences between the crops, the difference being less than 1% on all occasions. There was no evidence from this experiment that implementation of temperature integration increased stem *Botrytis*. A comparison of disease levels is given in the table below.

	Mean number of lesions per 100 stems	
	2002	2003
Temperature integration	9.4	0.55
Standard	11.8	0.31

1.1.18 Yield

The yield results from the trial were as follows:

	2002	**2003**
Treatment	**Yield – (kg/m^2)**	**Yield – (kg/m^2)**
Conventional	56.57	60.60
TI	59.03	61.84
Difference	2.3 (+4.3%)	1.24 (+2.0%)

Although this was not a fully replicated trial, confidence in the result for 2002 is increased as historical yield data from the nursery (pre 2002) showed less than 1% difference in yield between the two blocks. This is supported by specific factors directly connected to increased yield:

- 11% higher CO_2 level in the TI treatment.
- Less venting during cold weather, avoiding chilling the head of the crop and maintaining crop speed. The result being 2 extra trusses in the TI treatment.

In 2003 the TI treatment yielded 2% more than the control treatment. However unlike 2002, there were no supporting factors directly connected to increased yield. Therefore the difference was considered to be insignificant and for the purposes of assessing the financial benefit in 2003 the yield was considered to be the same in both treatments.

Discussion – a comparison of 2002 & 2003

Year 2 of this project demonstrated for a second successive year that TI can save energy without compromising crop performance. The higher yield in the TI treatment in 2002 was not repeated in 2003. This is because benefits relating to crop management seen in the TI treatment were applied to the control treatment in 2003. Specific areas were the avoidance of venting around dawn to activate the plant when outside temperatures were low and the equalisation of CO_2 levels between the treatments.

Yield comparisons between the two treatments over the two years of the trial are given in the table below.

	2002	**2003**
Treatment	**Yield – (kg/m^2)**	**Yield – (kg/m^2)**
Conventional	56.57	60.60
TI	59.03	61.84
Difference	2.3 (+4.3%)	1.24 (+2.0%)

Irrespective of a more focussed approach to crop management, drawing conclusions by comparing the yield in each year is confused by a wide range of factors including:

- Planting date was 3 weeks earlier in 2003.
- Light levels were 13% higher in 2003 during the important period between week 1 and week 10.
- Comparing the control treatment in each year, CO_2 levels were 16% higher up to week 10 due to the higher heat demand. But 7% lower for the remainder of the season due to higher outside temperatures and therefore increased ventilation.

In 2002 the approach to humidity control in the TI treatment was changed to a heat boost strategy. This ultimately proved to be unsuccessful and, as a result, a more conventional approach was used. Following this the TI treatment aimed to achieve the same level of humidity control but with a greater focus on ventilating in favour of using heat. In the conventional treatment a strategy based on increasing the minimum pipe temperature was retained as this was considered to be more in line with normal commercial practice.

In 2003 humidity control in both treatments was predominantly the same with the aim of always achieving what was considered as a safe humidity deficit. During the summer months of 2002 humidity control relied on venting in preference to heating in the TI treatment. This approach was applied to both treatments in 2003 whenever possible. The exception was between weeks 14 - 25 when outside temperatures at dawn were still low (<10ºC). In order to avoid chilling the head of the crop with cold outside air due to excessive venting, the minimum pipe temperature was limited to 50ºC and vent settings were applied so that air was gently bled in with a lee side vent of <3%. Even if this resulted in a low HD, it was tolerated as avoiding chilling the head of the crop was considered to be more important.

By week 26 in 2002 the disease risk was considered to be quite high whereas in 2003 good weather and a strong, clean crop meant that disease risk was low. As a result humidity controls during the evening and early parts of the night were relaxed. This was initially only applied in the TI treatment. However, because the results as far as energy saving (25%), glasshouse environment and crop/disease status were all positive, the approach was then also applied to the conventional treatment. This strategy was used until week 35 when conditions became less favourable and active humidity control was reinstated during the evening / early night period. At the end of 2003 the level of *Botrytis* was assessed. Results showed very low levels compared to those in 2002. Although the difference in 2003 was large in percentage terms, the difference in actual disease level was so small as to be considered insignificant.

	Mean number of lesions per 100 stems	
	2002	2003
Temperature integration	9.4	0.55
Standard	11.8	0.31

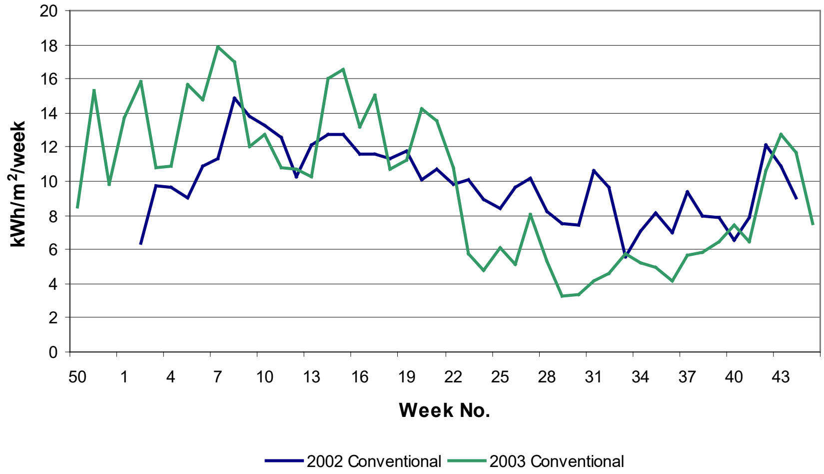
Comparing energy use between the two years is complicated by similar factors to those influencing yield comparisons such as:

- The earlier planting date.
- Different weather conditions.

Figure 13 overleaf shows energy use in kWh/m^2 of heat delivered to the conventional treatment in each year. Up to week 9 energy use in 2003 was typically 40% higher. This was due to a lower outside temperature in 2003 coupled with higher light levels. The increased global radiation helped to create a stronger crop that needed to be grown at a higher temperature, therefore compounding the effect of the lower outside temperature. Energy use was then similar until week 14 when the gro-pipe was turned on in 2003. This meant that energy was being delivered to the glasshouse to speed fruit ripening even when it was not required for temperature or humidity control. As soon as the gro-pipe was turned off in week 23, energy use dropped significantly and remained consistently lower than in 2002. This trend continued through to week 39.

This was aided by the relaxed approach to humidity control in the evening/early night and higher outside temperatures.

Figure 13 – 2003/2003 a comparison of energy use



Conclusions

The results of this project clearly demonstrate the potential of TI to achieve energy efficiency improvements when growing a commercial tomato crop. Over the two years of the trial the following key points have been illustrated:

- TI can be successfully applied to a commercially produced crop of heated tomatoes. Even by applying the technique in its simplest form, energy savings in the order of 5 to 8% can be expected.
- Better CO_2 utilisation may result from using TI. This is because TI leads to less greenhouse ventilation and hence better retention of CO_2 within the greenhouse.
- TI settings need to work in harmony with other greenhouse environmental control settings. This is particularly important where humidity control is concerned. This requires a good understanding of greenhouse environmental control and the subtleties of individual climate control computers. This may require investment in training for key staff and the devotion of greater management time on a week by week basis.
- When successfully applied, TI does not have a detrimental effect on crop yield or quality.
- Regular detailed crop recording (crop registration) can be a useful tool to help a grower quantify crop responses to short term effects. It also serves as a long term record of crop performance to aid planning for subsequent crops.
- By adopting the framework of settings illustrated in this project, growers can use TI on a commercial basis safe in the knowledge that crop performance will not be compromised.

Appendix 1 - Protected tomato: monitoring the effect of temperature integration on stem *Botrytis* 2002

Dr Tim O'Neill, ADAS Consulting Ltd.

Objective

To determine if temperature integration used during production of rockwool tomato cv. Encore, at Lansdale Nurseries Ltd, Scarisbrick, Lancashire in 2002, affects the occurrence of *Botrytis* in the crop.

Methods

Ten pathways in compartments 2 (standard) and 5 (temperature integration) were selected in April and a record maintained of the number of wilting or dead plant heads that were removed from each. The pathways were in the same relative position in each house and provided a spread through the houses, with equal numbers in left and right pathways and beneath vents and gutters. The total number of heads monitored (2 heads/plant) was 2,200 and 2,060 in compartments 2 and 5 respectively. On 30 September and 7 and 21 October, the number of non-wilting heads in each pathway was assessed. Additionally, on 7 October, assessments were made to determine the incidence of stem lesions/pathway, the infection routes (leaf scar, fruit truss or other) and the position of infection (counting fruit trusses from the stem base). Green and part-brown spent fruit trusses (30/compartment) with no sporing *Botrytis* evident on them were collected on 7 October and tested for *B. cinerea*. Means of % non-wilting plants were compared using a paired-sample t-test, comparing the results of rows at the same relative position in the two compartments. Lesion numbers were compared using a Mann-Whitney comparison of medians.

One spray of Scala was applied to both compartments in early May, followed by humidity reduction for 1 - 2 weeks, in an attempt to control *Botrytis* observed establishing on dead tissues in the crops. No other fungicides sprays were applied for *Botrytis* control.

Results and discussion

No *Botrytis* was observed in either compartment when the monitoring areas were marked out on 12 April. Sporing *Botrytis* was noted on dead flowers and leaves on 30 April (week 18) and the first dead stem was removed 3 weeks later (20 May). A severe attack of stem *Botrytis* subsequently developed. The number of dead wilted heads rose to c.1% by week 27 (1 July), 15% by week 40 (30 September) and to 30% by week 43 (21 October).

Comparison of *Botrytis* within compartments

On October 7, there was no significant difference (P>0.05) between the two compartments in the incidence of non-wilting heads (Table 1). The median number of *Botrytis* stem lesions/100 plants was slightly less in the temperature integration than the control compartment (P=0.078).

Table 1. Incidence of non-wilting plant heads and stem *Botrytis* lesions, 7 October

Compartment	Mean % non-wilting heads	Mean number *Botrytis* lesions / 100 stems
Standard	82.2 (1.93)	11.8 (0.83)
Temp. Integration	81.6 (0.93)	9.4 (0.77)
T value (12 df)	0.27	-
Probability	0.79	-

Standard errors are shown in parenthesis

Distribution of *Botrytis* within compartments

On 7 October, the incidence of non-wilting heads remaining in each pathway ranged from 69.0 to 86.9 (Table 2). No consistent effect of position relative to gutter or vent, or to left or right pathways was evident (Table 3). Possibly different levels of crop damage caused by different staff, or delay in removing dead plants, may account for the differences between individual paths. Contact spread of *Botrytis* in bundles of layered stems was observed in a few places.

Table 2. Distribution of non-wilting plants remaining after an attack of stem *Botrytis* – 7 October 2002

Compartment And row number	Position	% non-wilting heads remaining/row	
		Path A	Path B
Temp. Integration			
267	Gutter	85.3	82.2
261	Ridge	78.8	79.3
255	Gutter	84.8	80.3
249	Ridge	80.4	77.7
243	Gutter	86.2	81.2
Standard			
232	Gutter	81.9	69.0
226	Ridge	88.2	86.4
220	Gutter	83.7	74.2
214	Ridge	84.4	86.9
208	Gutter	84.8	82.2

Table 3. Mean effects of row position relative to glasshouse roof and path side on stem *Botrytis*

Compartment		% non-wilting plants		
		Path A	Path B	Mean
Temp. Integration	Gutter	85.4	81.2	83.3
	Ridge	79.6	78.5	79.05
Standard	Gutter	83.5	75.1	79.3
	Ridge	86.3	86.7	86.5

Origin and position of *Botrytis* stem lesions

Examination of the crop of 7 October showed that the majority of stem lesions present at that time arose from fruit truss die-back (88%). A smaller number arose at a stem split where the second head was taken (8%), or at de-leafing wounds (4%). Contact spread was also evident in some non-assessed rows.

When the position of stem lesions along the stem was examined (2 pathways/compartment) it was found that most arose from die-back of trusses on the lower third of the stems (trusses 1 - 8). This was the case for both the standard and temperature integration compartments.

Association of *Botrytis* with spent fruit trusses

Damp incubation confirmed the presence of *B. cinerea* on all 30 fruit trusses collected from each compartment. *B. cinerea* was recovered by isolation from the 60% of calyx detachment points of the green fruit trusses, and from 65% of junctions of green and brown tissue on part-brown trusses. Given the widespread occurrence of *Botrytis* in the houses on 7 October, the recovery of *Botrytis* from these dead tissues is not surprising.

Conclusions

Botrytis was first observed in the crop on 30 April 2002 and a severe attack of stem *Botrytis* had developed towards the end of cropping in October. No other stem diseases were found.

Monitoring of stem losses due to *Botrytis* (weeks 21 - 43), and the incidence of *Botrytis* stem lesions (week 41), revealed no differences between the temperature integration and standard compartments.

Stem *Botrytis* lesions arose predominantly from die-back of old fruit trusses.

Most stem rot arose on the lower one-third of plants (trusses 1 - 8).

Laboratory tests revealed that by 7 October *Botrytis* was commonly associated with green and part-brown fruit trusses that did not show sporing *Botrytis*, in both compartments.

Appendix 2 - Protected tomato: monitoring the effect of temperature integration on stem *Botrytis* 2003

Dr Tim O'Neill, ADAS Consulting Ltd.

Summary

Around 2000 stems in each of two adjacent compartments of tomato, cv. Encore, where one crop was being grown according to standard heating practice and the other was grown using temperature integration, were monitored for stem *Botrytis* from weeks 17 - 43. No fungicides were applied for *Botrytis* control. The occurrence of stem *Botrytis* was low, probably due in part to the exceptionally warm, sunny weather this year and to removal of old fruit trusses from stems during the season. On 6 October, the mean number of *Botrytis* stem lesions was less than one per 100 stems in both crops. At all assessments of the mean number of surviving, non-wilting heads, there were no statistically significant differences between the crops, the difference being less than 1% on all occasions. There was no evidence from this experiment that implementation of temperature integration increased stem *Botrytis*.

Objective

To determine if temperature integration used during production of rockwool tomato cv. Encore, at Lansdale Nurseries Ltd, Scarisbrick, Lancashire in 2003 affects the occurrence of stem *Botrytis* in the crop.

Methods

Ten pathways in compartments 2 (standard) and 5 (temperature integration) were selected in April and a record maintained of the number of wilting or dead plant heads that were removed from each. The pathways were in the same relative position in each house and provided a spread through the houses, with equal numbers in left and right pathways and a spread beneath the vents and gutters. The total number of heads monitored at full population (2 heads/plant) was 2,049 and 1,930 in compartments 2 and 5 respectively. These was reduced by 20% when the crop was thinned in week 30, the surplus stems being dropped onto the horizontal bundle of stems in week 39. The number of surviving, non-wilting heads was assessed in weeks 18, 20, 26, 31, 36 and 43. Each time a head was removed from the crop, the stem was examined to determine the probable infection route (e.g. leaf scar, fruit trusses and cracked stem). Means of % non-wilting plants were examined using a paired-sample t-test, comparing the results of rows at the same relative position in the two compartments.

In contrast to 2002, the majority of old fruit trusses were pulled off as they occurred, from week 20 onwards. No fungicides were applied for *Botrytis* control. Bavistin DF was applied as a root drench treatment on 30 May, against Verticillium wilt in one area of compartment 2.

Results and discussion

No *Botrytis* was observed in either compartment when the monitoring areas were marked out in early April. Spent trusses (green) were collected on 22 April and tested for latent *Botrytis*; none was found. Leaf debris with sporulating *Botrytis* was observed in the crop in weeks 31 and 36 (both in the temperature integration compartment). The first dead stems were observed and removed in week 20 (mid-May).

Throughout the season, *Botrytis* stem lesions occurred at only a very low level in both compartments.

Comparison of *Botrytis* within compartments

The number of live plant heads remaining, expressed as a % of the original plant population, is shown in Table 1. The difference between the two compartments was less than 1% at all assessments. There were no statistically significant differences between the two compartments.

Table 1. Incidence of non-wilting plant heads – 2003

Compartment	% live heads remaining*			
	Week 26	31	36	43
Temperature integration	96.9	93.9	73.4	70.8
Standard	96.9	94.5	73.8	70.5
T-value	0.10	0.51	0.51	0.38
Probability	0.92	0.62	0.62	0.71

*Decline between weeks 31 and 36 is largely due to crop thinning by 20%.

The cumulative number of stems removed with time, expressed as a % of the original plant population is shown in Table 2. These figures indicate a slightly greater removal of dead stems from the control than the temperature integration compartment, increasing as the season progressed. The assessment of % live heads remaining is probably a more accurate measure of damage from *Botrytis* as not all dead or wilting plant heads are immediately removed from the crop.

Table 2. Cumulative incidence of plant heads removed – 2003

Compartment	Cumulative % wilting or dead heads removed					
	Week 18	20	26	31	36	43
Temperature integration	0	0.4	3.6	5.0	8.2	10.5
Standard	0	0.8	4.3	6.6	12.0	15.7

On 6 October, the number of *Botrytis* stem lesions/100 live stems was very low (less than 1) in both compartments (Table 3). The proportion of live (green) stem bases at this time was slightly greater in the temperature integration (97.9) than in the standard compartment (95.1).

Table 3. Incidence of *Botrytis* stem lesions, 6 October

Compartment	Mean number of lesions per 100 stems	Origin of lesions			
		Leaf scar	Fruit truss	Split Ste m	Other
Temperature integration	0.55	3	13	1	1
Standard	0.31	3	3	4	1

Distribution of *Botrytis* within compartments

In week 43, the incidence of non-wilting heads remaining in each pathway ranged from 66.2 to 74.7. Overall, there were around 3% more surviving non-wilting heads under ridges than under gutters, and around 1.5% more in path A than path B (Table 5). Possibly different microclimates under ridges and gutters, or levels of crop damage caused by different staff, or delay in removing dead plants, may account for these differences.

Table 4. Distribution of non-wilting plants, week 43, 2003

Compartment and row number	Position	% of non-wilting heads	
		(Path A)	(Path B)
Temperature integration			
267	Gutter	73.3	70.5
261	Ridge	74.1	72.7
255	Gutter	67.9	68.9
249	Ridge	74.7	66.2
243	Gutter	70.3	69.9
Standard			
232	Gutter	70.4	66.7
226	Ridge	73.5	74.6
220	Gutter	69.9	68.6
214	Ridge	70.8	72.7
208	Gutter	69.1	68.9

Table 5. Mean effects of row position relative to glasshouse roof and path side on non-wilting plants – week 43, 2003

Compartment	% heads present and not wilting		
	Path A	Path B	Mean
Temperature integration			
Gutter	70.5	69.8	70.2
Ridge	74.4	69.5	71.9
Standard			
Gutter	69.8	68.1	68.9
Ridge	72.2	73.7	72.9
Mean			
Gutter	70.2	68.9	69.6
Ridge	73.3	71.6	72.5

Origin of *Botrytis* stem lesions

Over the season as a whole, where the origin of plant head death from *Botrytis* was identifiable on the stem, most lesions appeared to originate from broken stems (18.5%), leaf scar infections (9.4%) or from fruit truss die-back (7.3%) (Table 6). For many of the stems (63%), it was not possible to determine the probable origin of stem death at the time it was removed.

Table 6. Origin of *Botrytis* stem lesions – 2003

Compartment	Incidence of lesions as % of total					
	Leaf scar	Fruit truss	Broken stem	Side shoot	Contact	Unknown
Temperature integration	4.8	13.8	12.4	1.4	1.9	65.7
Standard	12.6	2.9	22.5	0.3	0.9	61.2
Mean	9.4	7.3	18.5	0.7	1.3	63.1

Spore trapping

Ten plates of *Botrytis*-selective agar were left exposed for 3.5 hours (11.30 – 15.00) in each compartment on 6 October. No *Botrytis* colonies developed on subsequent incubation of plates. This reflects the very low level of *Botrytis* observed in the crop at that time.

Conclusions

Stem *Botrytis* was first observed in the crop in mid-May but developed little during the season. This was in marked contrast to 2002. No other stem diseases were found. Verticillium wilt was confirmed on a few plants in non-assessed rows in compartment 2.

Monitoring of the decline in a number of viable heads revealed no statistically significant differences between the temperature integration and standard compartments.

Removal of old fruit trusses from plants, soon after the last fruit was harvested, appeared to be effective at preventing stem *Botrytis* occurring via this infection route. The exceptionally warm and sunny weather during 2003 probably also contributed to the lack of a significant *Botrytis* problem.

Appendix 3 – PC 188a: Summary of plant response 2002 and subsequent goal settings and results for 2003

Dr Andy Lee, Grodan & Nic van Roosmalen, Substratus bv

Action points for growers

- Do not think of temperature integration (TI) as a way of saving energy. Look at TI as a means of creating a better climate for the crop.
- The benefits of TI (retaining solar heat in the glasshouse) and thereby energy saving will be maximised in the spring and the autumn if the crop density is correctly matched to the available light. Consequently (solar) temperature can be maintained (or raised) in the glasshouse during the spring. If the crop density is too great solar heat would need to be vented away in order to maintain power (stem diameter) in the crop thereby wasting "free energy".
- Revisit and adapt, if required, your agronomic practices. Optimising the production system in line with the production goals of the nursery may go a long way to achieving the required increases in productivity levels (kWh/kg) that are required to keep the 50% CCL rebate beyond 2005.
- Crop registration is a useful tool which allows growers to make informed decisions in respect to the cultural strategy both prior to planting (the planning phase) and during the season (the tracking phase) in order to reach the desired production goals.

Introduction

A major goal of project PC 188 was to "quantify any crop related effects towards TI". In order to identify how the crop responded crop registration was used.

Crop registration in its broadest sense is a term used to describe the weekly recording of the external and internal climates as well as a number of key plant measurements. By measuring the plant and using the data to create simple graphics the grower can see how the crop is reacting to the climatic influences imposed on it. By interpreting this information the grower is then able to assess the 'balance' of the crop prior to making any necessary changes to the growing strategy, namely:

- Is the crop weak or strong?
- Is the crop vegetative or generative?
- What was the trend in crop development over the last three weeks?
- Did the changes in the climate strategy I made last week have the desired effect?

Figure 1 shows how the balance of the crop can be assessed using such data presented in graphical format.

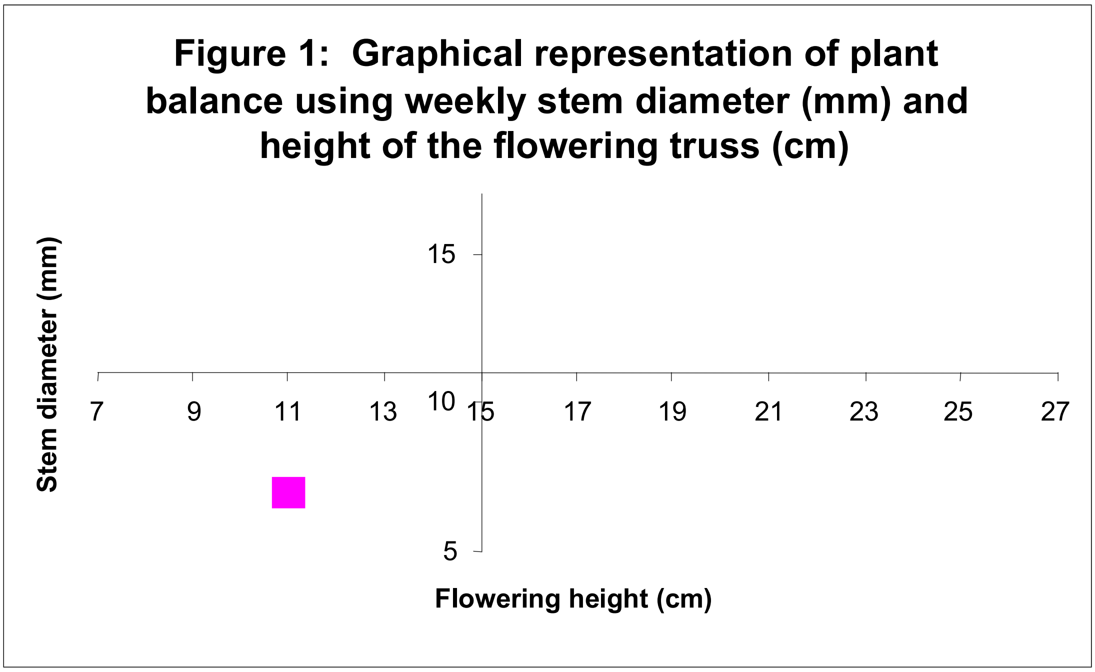


Figure 1: Graphical representation of plant balance using weekly stem diameter (mm) and height of the flowering truss (cm)

Figure 1: Balance in the crop is measured by the height of the youngest flowering truss this figure is shown along the X axis. If the height of the flowering truss is >15 cm the crop would be described as vegetative. If the height of the flowering truss was <15 cm the crop would be described as generative. Power in the crop is measured from the stem diameter this is shown on the Y axis. If the stem diameter is <11 mm the crop would be described as weak if the stem diameter >11 mm the crop would be described as strong. Thus in the example above the data point shown describes a crop which is tending to be weak and generative.

Simply being able to answer these basic questions and observe the pattern of crop development over the course of several weeks allows the grower to steer the crop in the optimum direction, optimising the use of the available inputs namely the heating strategy (i.e. higher or lower), the irrigation strategy (i.e. wetter or dryer) and labour strategy (i.e. more leaves or less leaves).

Summary of the crop response 2002

A detailed analysis of the crop response in 2002 was undertaken and presented at an HDC Seminar *"Energy saving for protected salad growers*", (HDC, 2002). The following is a brief summary of the major conclusions drawn. Analysis of the 2002 crop registration figures demonstrated that the yield benefits obtained from TI over the control treatment were achieved by:

- Higher day time temperatures as a result of the higher ventilation set points demanded by TI

that in turn led to

- Higher day time CO_2 levels.

Consequently the crop was able to make better use of the available light.

On cold bright days in the spring the higher ventilation set point also prevented the TI treatment experiencing the "cold air effect" (i.e. cold outside air falling onto the heads of the crop). In contrast it was found that, because an aggressive ventilation strategy had been used in the conventional treatment during the spring, such an effect had occurred in the 'control' crop.

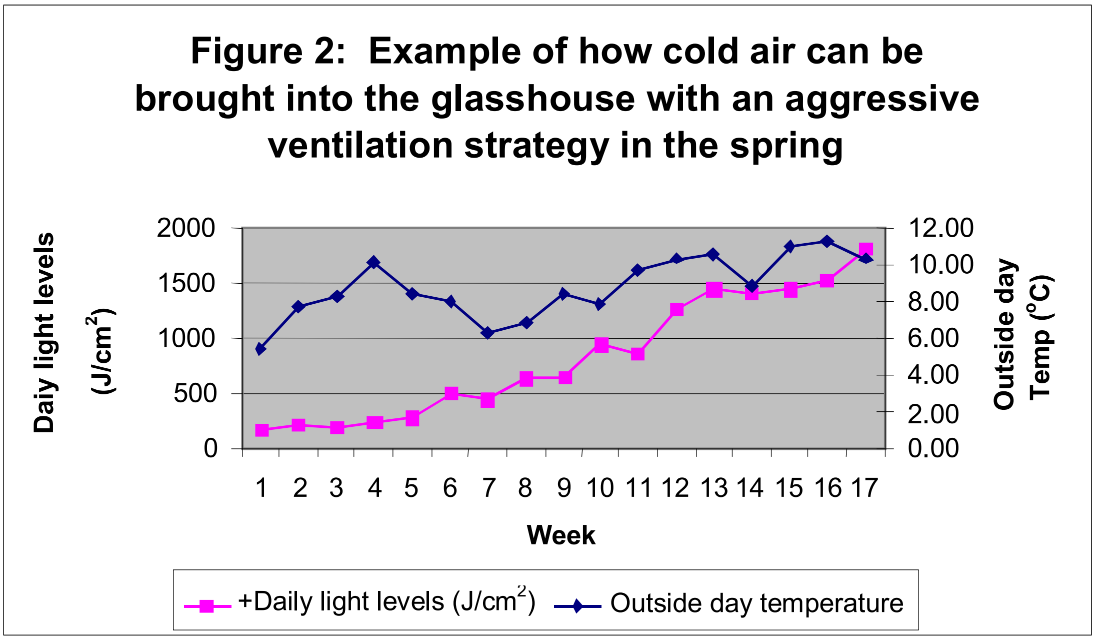


Figure 2: "The cold air effect": solar radiation rises rapidly from week 10 however the outside temperature is still low 10 - 11^{oC}. Aggressive ventilation during this period results in cold air falling onto the heads of the crop. Transpiration ceases as the stomata close and consequently photosynthesis is reduced and productivity is lost. Cold air also increases the risk of Botrytis infection in the heads. Having a pipe temperature hot enough would force air out of the glasshouse but this strategy requires a large input of energy.

The improved efficiency of the TI treatment to turn light energy into fruit was expressed by the crop having:

- A greater flowering speed, consequently it produced more trusses per m^2 and by the end of the season had produced an additional truss compared to the control treatment.
- Although the commercial nature of the trial did not allow the differences in mean fruit size between treatments to be recorded, we can assume that, because the TI crop experienced a larger day / night temperature differential (in order to keep the 24-hr temperature in the two treatments the same), the average fruit size was larger. One can also assume that fruit size would have been larger due to the higher CO_2 levels experienced by the crop. Indeed Lansdale Nurseries Ltd did perceive fruit size to be larger in the TI treatment.

The combined effect of an extra truss at the end of the season and a (assumed) larger fruit size were the primary cause of the yield gains seen in 2002.

Common trends within the cultural strategy

A detailed analysis of the crop registration data showed that there were common trends in the general cultural strategy which was not treatment specific. These related to the flowering speed of the crop and average fruit size, parameters which, as we have discussed, make up the total yield of the crop at the end of the season.

The flowering speed of the crop is related to 24-hr temperature and plant balance. For example a higher 24-hr temperature will result in a faster flowering speed and vice versa. However a weak or vegetative crop will have a slower flowering speed compared to one which is in balance at the same 24-hr temperature. The flowering speed related to 24-hr temperatures for any given crop which is in balance is shown in Table 1.

Table 1: Weekly flowering speeds (trusses per week) for a balanced crop in relation to the 24-hr glasshouse temperature.

24-hr glasshouse temperature	Flowering speed / set speed of the crop
17^{oC}	0.7
18^{oC}	0.8
19^{oC}	0.9
20^{oC}	1.0
21^{oC}	1.1
22^{oC}	1.2

The mean flowering speed for both the control and TI treatments in the 2002 trial was judged to be too low (0.8 trusses per week), especially during the spring and autumn. This was because the head density (fruit load) was not matched to the available light, i.e. the density was increased too quickly in the spring and was maintained at a high level during the autumn.

The effect of increasing the head density too quickly and maintaining it at a high level in the autumn was also seen by the reaction of the plant, namely:

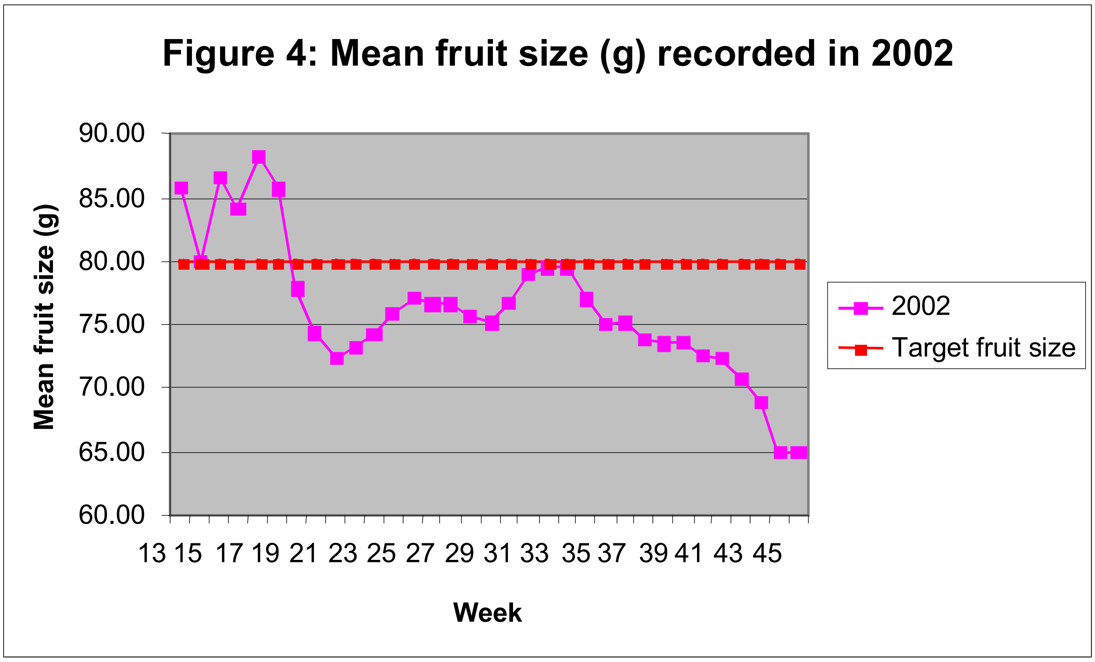
- Truss development (Figures 3a and 3b). It was observed that truss development beyond the 6^{th} truss produced predominately six not eight fruits (Figures 3a), i.e. the plant was trying to balance itself in terms of the number of fruit that it could support. Short trusses may also have been a contributing factor to *Botrytis* infection as a result of truss die back.

Figure 3a "full truss"

Figure 3b "short truss"

Figure 3a and 3b: Encore should produce 8 - 9 marketable fruits per truss (Figure 3a). Increasing the density too quickly causes the plant to make "short trusses" (Figure 3b), i.e. there is no gain from increasing the density too quickly.

- Target fruit size of 80 g was not achieved (Figure 4).



- The plant became weak in the autumn. Consequently the risk for *Botrytis* infection was increased. It is important to remember that *Botrytis* is a "weakness fungus" it affects dead or dying plant tissue.

In conclusion there was no benefit gained from adopting the growing strategy of planting the crop at 2.0 plants /m^2 and doubling the head density at the first truss shoot to 4.0 heads /m^2 and trying to maintain this density for the remainder of the season.

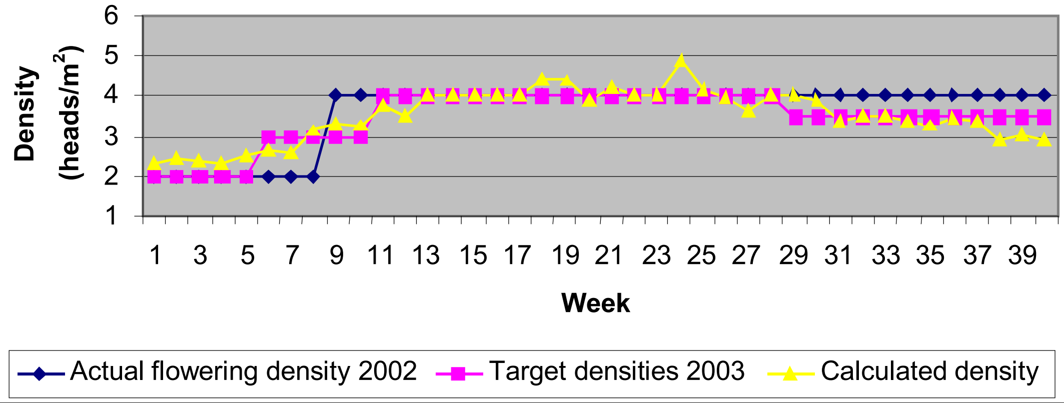
Learning from the lessons of 2002: planning the cultural strategy for 2003

Production potential

In order to grow a successful crop a growing strategy is required, basically a production plan with tangible goals attached. The data collected from crop registration was used to plan such a strategy for the 2003 crop. In order to devise the strategy the average light levels recorded at Lansdale Nurseries Ltd were used as a starting point. The plan clearly demonstrated, on paper at least that the production potential of a crop cv. Encore grown on this site should yield 61.0 kg/m^2. Thus, despite achieving a yield of 59.03 kg/m^2 , the TI treatment still fell sort of the "optimum" crop for the reasons described above.

The number of fruits set per m^2 is obviously a function of the plant density and flowering speed. A theoretical plant density was calculated taking into account the available light and target fruit size. This was used to plan the densities in 2003 (Figure 5).

Figure 5: Calculated flowering (head) density (m^2) compared to actual densities in 2002 and the recommended target densities for 2003 to achieve mean fruit size 80g



Subsequent changes in the growing strategy compared to 2002

Major changes compared to the 2002 crop were the phased introduction of additional heads in weeks 5 and 11 in both treatments, thus keeping head density (fruit load) in line with the increasing light levels (Figure 5). Crop registration was then used to track the progress of the crop. In all 10 plants from each treatment were recorded.

Crop details

Variety:	Encore (DeRuiter Seeds)
Sown:	14 November 2002
Introduced to glasshouse:	12 December 2003
Slab contact:	16 January 2003
Initial plant density:	2.0 plants/m^2
First shoot:	3.0 heads /m^2 week 5 flowering by week 7
Second shoot:	4.0 heads /m^2 week 11 flowering by week 13
Density reduced:	3.1 heads /m^2 week 31 (but planned for week 29)
All plants stopped:	week 38

Substrate:	Grodan Master
Profile:	Soil
Plant arrangement:	V-system

Crop goals 2003

Target fruit size:	80g in both treatments
Target yield:	60.0 kg/m^2 in both treatments

Stem diameter:	range 10-11 mm
Height flowering truss:	range 12-15 cm

These two parameters were subsequently used as the main crop steering goals within the growing strategy.

Results

Crop balance

Figures 7a and 7b describe the weekly balance of the control and TI treatments respectively in the spring, summer and autumn. Each point represents the weekly mean recorded flowering height and stem diameter for the 10 recorded plants in each treatment.

Figure 7a: Weekly balance and power in the spring, summer and autumn compared to the defined production goal: Control crop

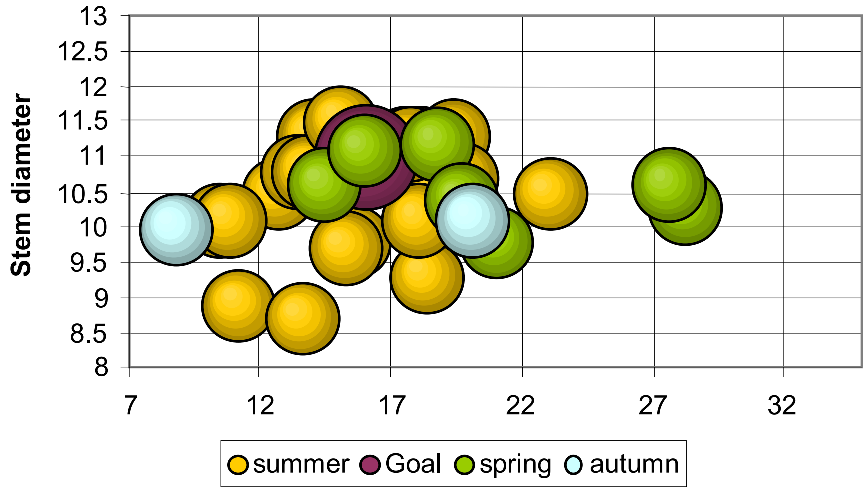
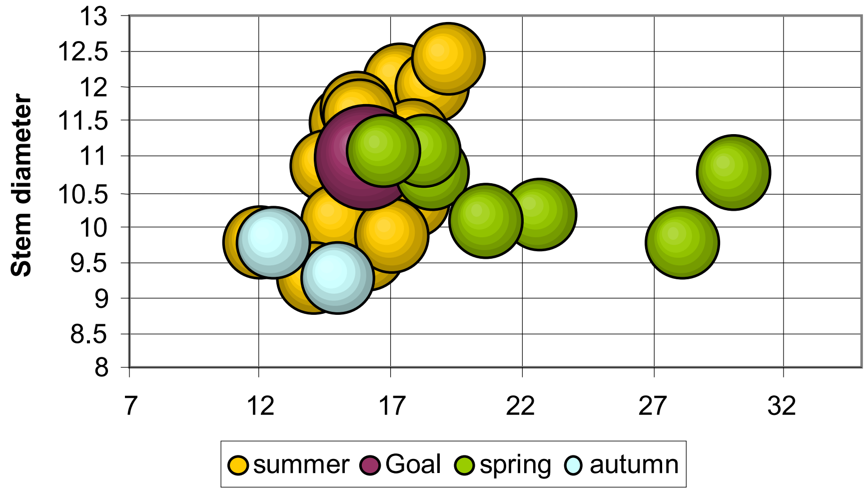


Figure 7b: Weekly balance and power in the spring, summer and autumn compared to the defined production goal: Integrated crop



To enable all plants to be "driven" at the same speed (temperature) and to keep the correct balance in the crop, the plants where the side shoot was taken in week 5 were truss pruned. This also helped to prevent the fruit load increasing too quickly.

A site visit in week 8 determined that the TI treatment was more in balance than the control. Therefore, to achieve the correct balance in the control crop, the temperature strategy was changed. This was to heat longer into the day and to create a larger day/night differential (Figure 8). Thus the heating strategy worked more on fruit production rather than leaf production and consequently balance was restored. This basically applied some of the principles of TI without using the facilities of the Priva Integro program.

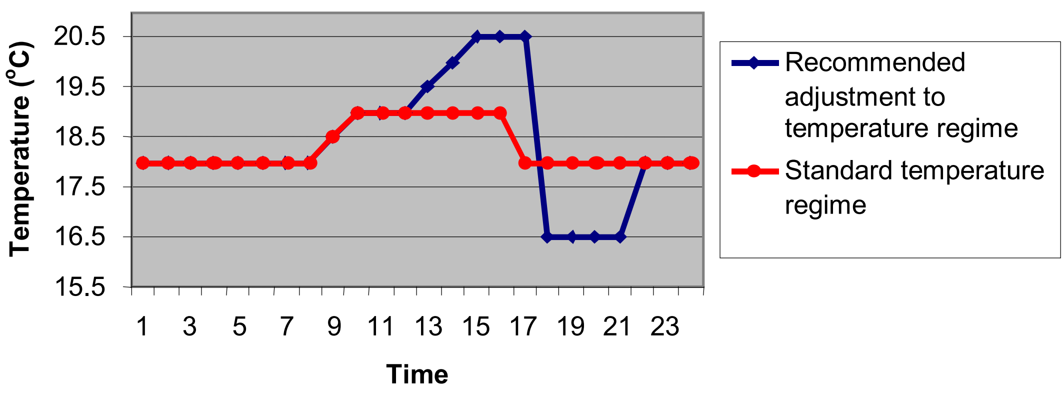


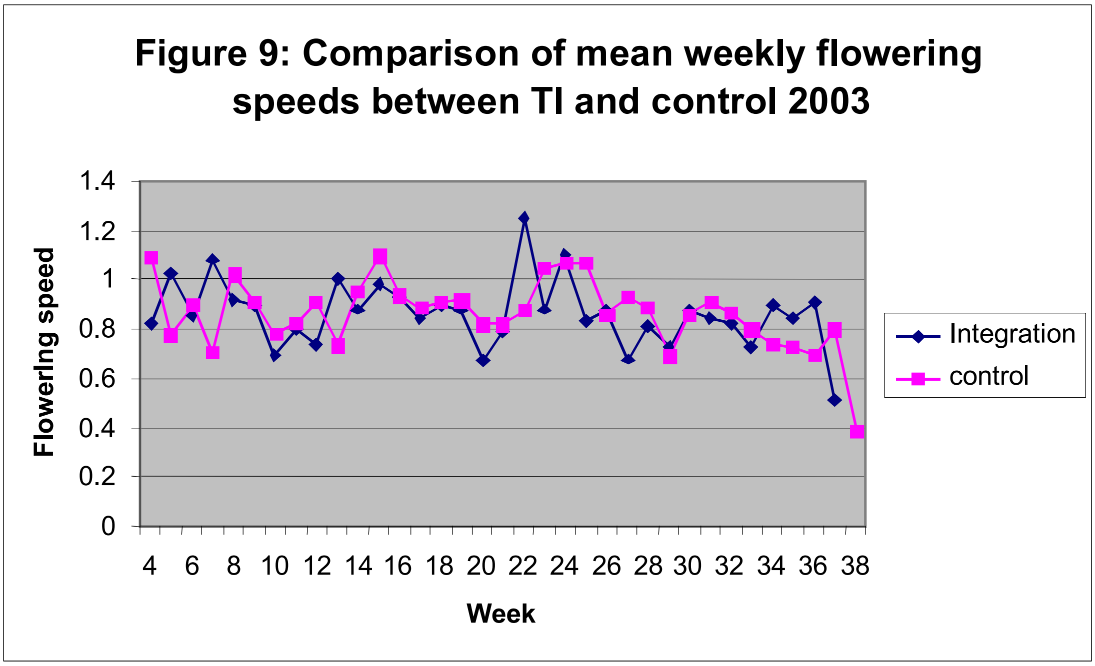
Figure 8: Adjustments to the general growing strategy in week 9 to improve the balance in the control treatment

In both treatments a leaf was removed from the head of the plant from the 3rd truss. This opened up the plant canopy and allowed light to penetrate its entire depth. Leaf picking was stopped in week 16 as the leaf number was increased in preparation for the summer.

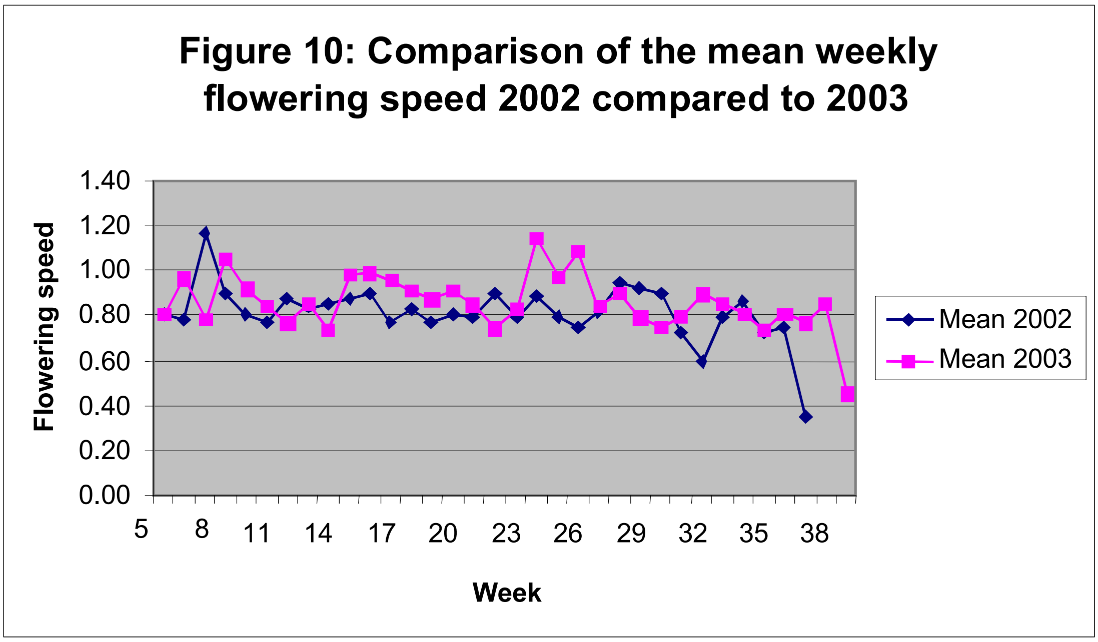
During the summer the balance of the TI crop was better than the control. This is evident as less scatter around the pre-determined goals set prior to planting (Figure 7b). In the autumn both crops showed signs of weakening before all of the heads were finally removed in week 38. The head density was reduced in week 31, due to labour planning, and not as recommended in week 29. It is however a good indicator that reducing the head density to 3.1 heads m^2 was the correct strategy.

Flowering speed

Unlike 2002 there was no treatment effect on flowering speed during the spring. This is probably due to the improved growing strategy in the control block. However there was still an unexpected dip for both treatments between weeks 11 - 13. This is the time when the last shoot was beginning to flower with the crop at 4.0 heads /m^2 (Figure 9) suggesting that maybe 4.0 heads /m^2 is still too high, a theory supported by the fall in flowering speed after the longest day (Figure 9).



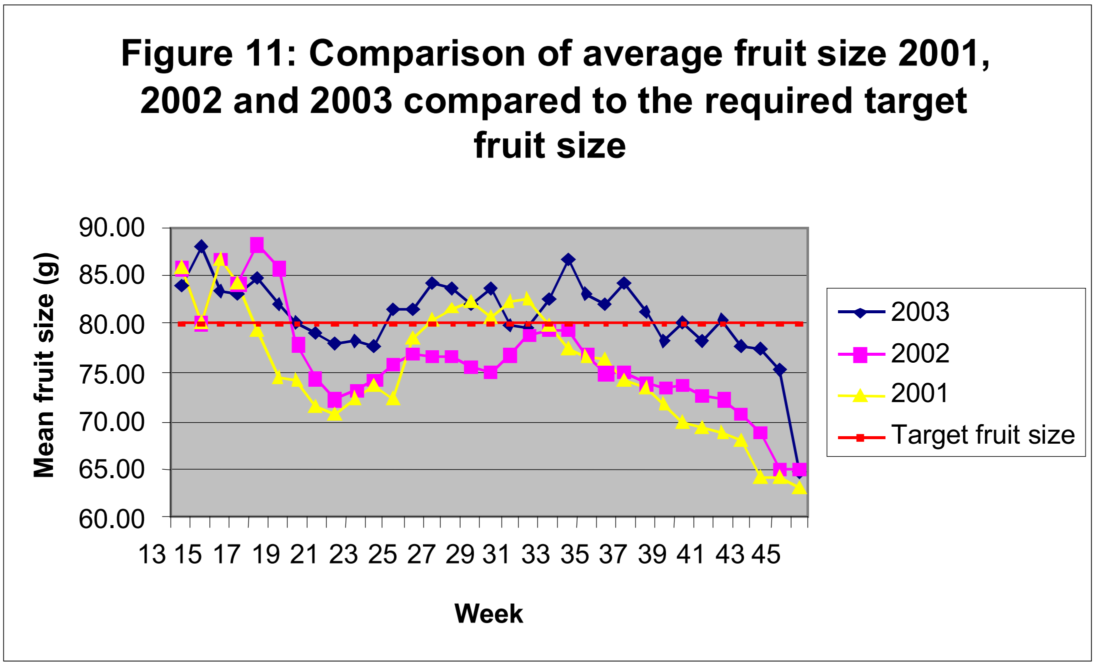
However an analysis of the mean weekly flowering speeds of both treatments between the two years clearly indicates the improvements made in 2003. This can be attributed to the manipulation of head density and hence a targeted fruit load which was more in line with the available light (Figure 10).



Fruit size

First harvest was approximately one week later than that predicted when planning the growing strategy prior to planting. On investigation the growing pipe had been switched off as the energy input through it could not be measured for the purposes of the trial. Following a site visit in week 14 the growing pipe was switched on at 50^{oC}.

Consequently due to the prolonged ripening time the initial fruit size was larger than that targeted (Figure 11). However because the fruit load was correctly matched to the available light the mean weekly fruit size was much closer to target (80g) than in the previous two growing seasons (Figure 11).



Unfortunately as in 2002 the mean fruit size for the individual treatments could not be recorded due to the commercial nature of the trial. However it is assumed that the difference between the two blocks was smaller than in 2002 due to the improved growing strategy of the control treatment. This is further reflected in the total yields of each treatment.

Number trusses per plant

There was no difference in the number of trusses produced per plant in 2003 between the two treatments (Table 2). However comparing the number of trusses produced between 2002 and 2003 it can be seen that by maintaining a higher flowering speed during 2003 an additional 3.6 trusses per m^2 where set per plant when comparing the two TI treatments (Table 2).

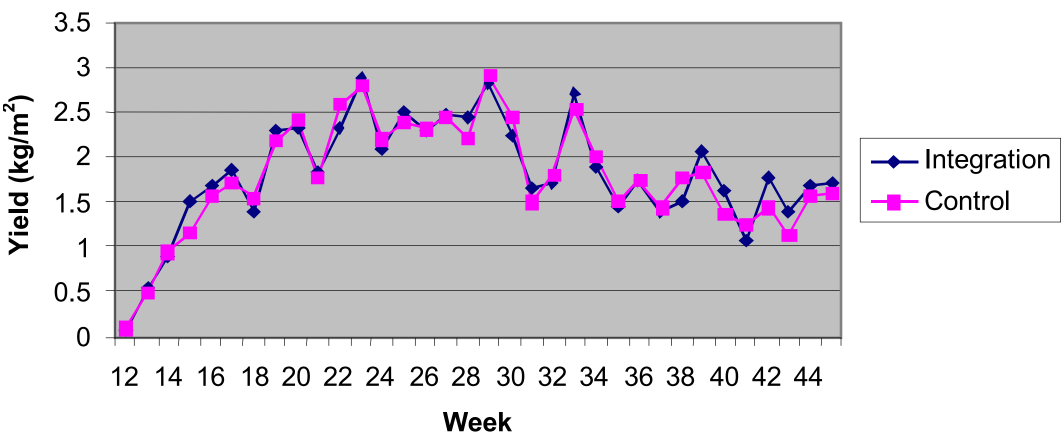
Table 2: Number of trusses produced 2002 compared to 2003 for each treatment

Treatment	Number trusses produced per plant
Control 2002	24.80
TI 2002	26.88
Control 2003	30.36
TI 2003	30.56

Yield

There was little difference in weekly marketable yield (Figure 12) and it is unlikely that there was any significant treatment effect.

Figure 12: Comparison of weekly yield (kg/m^2) between TI and control



The crop yield for 2001 in the same location (mean of the two total trial areas) is also shown for comparison in Table 2. It can be seen that this was similar to the control treatment in 2002. Taking 2001 as a base year simply changing the ventilation strategy and placing a greater emphasis on the crop the productivity levels at Lansdale Nurseries Ltd has risen 4.9 % (Table 3).

Table 3: Yield (kg/m^2) summary and fuel use for Lansdale Nurseries Ltd 2001, 2002 and 2003.

	2001	2002		2003	
	Control	Control	TI	Control	TI
Yield (kg/m2)	57.77	56.57	59.03	60.60	61.84

Conclusions

The lessons learnt from manipulating the climate strategy in 2002 via TI were carried forward into 2003. Consequently there was little effect in terms of measured plant response to the treatments in 2003. This would be expected as the crop manager adapted his method of production to the benefit of Lansdale Nurseries Ltd.

Aggressive ventilation for humidity control was avoided using a larger P-band in combination with TI in the spring thus cold air did not fall onto the crop. In 2003 the head densities in both treatments were in line with the available light subsequently crop speed was greater and fruit size was maintain closer to target. However the unexpected dip in flowering speed between weeks 11 - 13 and again after the longest day (Figure 9) suggests that a final head density of 3.5 – 3.6 may have been more suitable.

The increase in yield and productivity levels at Lansdale Nurseries Ltd over the base year 2001 can be attributed to the wholesale change in crop planning and crop steering. Thus despite having 25% fewer heads over the duration of the season compared to 2002 the target goal of 60kg/m^2 was achieved.

In this respect one should not discount the added benefits of maintaining a targeted fruit size. It was noted the grading times were reduced and hence grading costs were also reduced as was the amount of waste product.

It is generally accepted that 2003 was not a *Botrytis* year in the UK due to the higher light levels. However one must remember that *Botrytis* affects weak plants and in this respect Lansdale Nurseries Ltd were less susceptible to infection because they grew a generative, warm crop in the spring. Balance was maintained throughout the growing season through manipulation of fruit load consequently the crop did not become weak and susceptible to infection in the autumn.

This project clearly demonstrates the value of how crop registration information can be used in conjunction with energy conscious strategies to assist growers in planning and tracking the cropping strategy during the season.

References

van den Berg, G.A., Buwalda, F. & Rijpsma, E.C. (2001). *Practical demonstration Multi-day Temperature Integration*. PPO 501. Praktijkonderzoek Plant & Omgeving, Wageningen, The Netherlands, 53pp.

Plackett, Adams, Cockshull (2003). *A technical & economic appraisal of technologies & practices to improve the energy efficiency of protected salad crop production in the UK.* HDC – PC 188.

O'Neill, Pettit, Hamer, McQuicken, Shaw, Barnes (2002*). Integrated Chemical & Environmental Control of Grey Mould (Botrytis cineria) in Protected Container Grown Ornamentals*. Hortlink HORT25, HDC PC/HNS121, DEFRA CSA4189.

Cockshull, K.E., Adams, S.R., & Plackett, C.W. (2002). *Smart temperature control*. Grower (03.10.02), 20-21.

Pratt, Plackett & O'Neill (2003). *A technical & economic appraisal of technologies & practices to improve the energy efficiency of protected salad crop production in the UK. Part B – A demonstration of advanced environmental control strategies.* HDC Project Report PC 188 Part B