

Project title: Protected Ornamentals: Improved guidelines for humidity control and measurement and control when using advanced climate control strategies

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Grower Summary

1 Headlines

Year 1 - 2003

A good quality Poinsettia crop was grown using Temperature Integration (TI). An energy saving of 16kWh/m² (12%) was achieved and no humidity control or humidity related disease problems were evident.

Year 2 - 2004

TI was successfully used for a second consecutive season. Humidity control based on measurements taken in the plant canopy gave a significant reduction in the level of latent botrytis.

2 Background & expected deliverables

- This project demonstrates the application of TI on a commercial Poinsettia nursery. It tackles growers concerns with regard to humidity control problems when using energy saving strategies like TI and builds on the findings of PC 190, “Protected Ornamentals: Investigation into the potential savings available from adopting energy optimisation principals in UK glasshouse production”.

The project objectives were to:

- Demonstrate that it is possible to achieve improved humidity, disease control and energy savings while applying temperature integration.
- Promote an improved understanding of the fundamental principles of effective humidity control.
- Develop improved guidelines for measuring and controlling humidity in commercial greenhouses producing ornamental crops.
- Generate new information to train protected crop growers in improved greenhouse environmental control and energy management.

3 Summary of project and main conclusions

3.1 Research method

A commercial Poinsettia crop (cv Sonora) was grown in two greenhouses in the 2003 & 2004 cropping seasons. The work was carried out at Coletta & Tyson Ltd, Millbeck Nursery, South Cave, East Yorkshire. Each treatment covered an area of 4,570 m².

3.1.1 Year 1 (2003)

- **Conventional control.**
- **Temperature integration (TI).**

In both of the treatments temperature & humidity control were based on measurements taken with conventional sensors positioned 30 cm above the crop canopy.

An investigation was also carried out into the performance of the following alternative temperature and humidity measurement techniques:

- **Electronic humidity sensor** – The accuracy of this new type of sensor was compared to the traditional wet and dry bulb temperature arrangement.
- **Canopy measurements** – To measure the true conditions within the crop, simple modifications were made to a traditional measuring box. This involved attaching a manifold to sample air from within the crop canopy (see figure 1).
- **Infrared camera** – This measures the canopy surface temperature (see figure 2).
- **Crop canopy temperature probes** – a simple temperature probe was positioned adjacent to the plant stem (see figure 3). This was tested as a low cost alternative to the infrared camera.



Figure 1: Canopy measuring box



Figure 2: Infrared camera



Figure 3: Canopy temperature probes

3.1.2 Year 2 (2004)

Following assessment of the results from year one, the following treatments were applied.

- **Standard TI.** In this treatment humidity control was based on the measurements taken using a conventional measuring box suspended 30 cm above the crop canopy.
- **Canopy TI.** In this treatment humidity control was based on the measurements taken from within the crop canopy.

3.2 Results

3.2.1 Energy

In year 1 the conventional treatment used 136 kWh/m² compared to 120 kWh/m² for the TI treatment. A saving of 16kWh/m² (12%) was therefore made between weeks 36 and 50.

In year 2 the 'Standard TI' treatment used 136 kWh/m² compared to 134 kWh/m² for the 'Canopy TI' treatment. Therefore a saving of 2kWh/m² (1.5%) was made between weeks 36 and 50.

3.2.2 Humidity and temperature measurement methods

3.2.2.1 Conventional measuring box

This gives poor information about the actual conditions experienced by the plant. This is especially the case when the crop canopy is fully developed and when radiant heat loss from the crop is high (i.e on clear nights when the greenhouse does not have a closed screen).

3.2.2.2 Canopy measuring box

The information given by this technique is different to that from conventionally positioned sensors. This is especially the case when the crop canopy is fully developed. This is because the crop restricts air movement between the canopy and the airspace above. There is no consistent difference between the humidity measured at the conventional position and that measured in the canopy. Therefore, applying a simple offset (e.g. assuming that the Relative Humidity is always 5% higher within the canopy) is not satisfactory.

3.2.2.3 Electronic humidity sensor

This sensor gave accurate information when compared with the traditional wet & dry bulb sensor in the same air stream. One of the sensors was unreliable but a second continued to give accurate readings 16 months after installation. Rapid technology development means that the specific sensors used in this project are now obsolete. Current commercial sensors should be more reliable, although this project provides no specific information to confirm this.

3.2.2.4 Infrared camera

The infrared camera was found to work best once a full crop canopy had developed and, with a young crop, the camera needs careful positioning to be effective.

The most significant differences in plant temperature occur during periods of high or rapidly changing light conditions. However, the ability to change heating or ventilation settings in response to such variations is limited. As a result, the value of infrared temperature measurement as a control parameter is questionable.

On the other hand, infrared measurements could provide a useful indication of plant activity or stress and give information to allow the grower to change the growing strategy.

An infrared measurement of canopy surface temperature on a cold night with clear skies illustrates the level of radiant cooling that can occur in a greenhouse without screens. In these conditions it is common to measure a canopy surface temperature 1°C less than the conventionally measured temperature. Comparing this to the dew point of the air can give an indication of the likelihood of condensation on the crop and therefore potential disease risk.

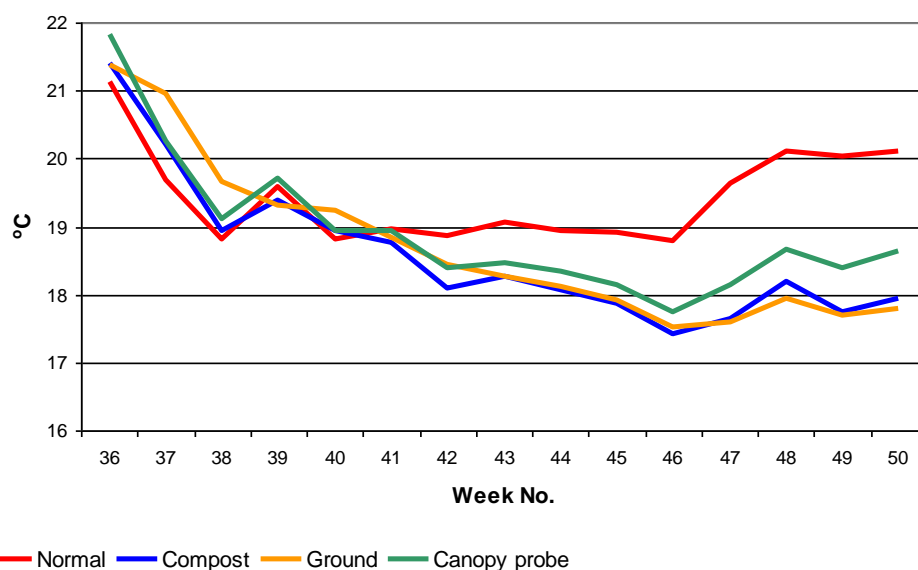
3.2.2.5 Canopy temperature probes

These are reliable, simpler and cheaper than an infrared camera. This approach is therefore a cost effective starting point for any grower that wants to look more closely at the true crop environment.

Figure 4 below illustrates how information from canopy temperature probes can provide information to help save energy. The graph shows the average weekly temperatures measured at four locations and highlights that, from week 42 onwards, the air temperature was much higher than the canopy temperature. This was due to the cooling effect of the ground.

With this in mind, if the crop were raised off the ground, the cold floor would not influence the canopy temperature. This would allow a lower greenhouse temperature to be used and energy to be saved.

**Figure 4 –
Average
temperature,
Normal vs IR &
Probe**



3.2.3 Humidity / disease control

3.2.3.1 2003

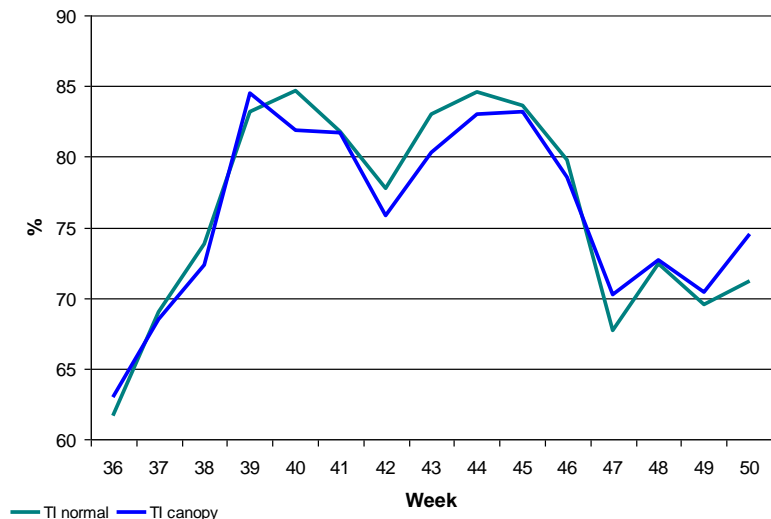
Satisfactory humidity control was achieved in both treatments. There was no notable difference in disease (*botrytis*) between treatments.

3.2.3.2 2004

The most significant difference between the two humidity control methods occurred during the post-drop period when high humidity air trapped within the canopy meant that active humidity control continued for longer in the 'Canopy TI' treatment.

Figure 5 shows the average humidity during this part of the day. Significant differences were seen from week 40, once a fully crop canopy had developed, to week 47. After week 47 the drop period was removed and the humidity was lower due to high heat demand for temperature control.

Figure 5 – Average RH, early morning



3.2.4 Crop performance

3.2.4.1 2003

Pre-marketing quality assessments and shelf-life tests showed small but conflicting differences between each treatment. On site crop grade-out figures showed no difference between treatments and the crops were considered to be of the same quality.

3.2.4.2 2004

Although there was some variation between treatments in specific criteria, neither was consistently better or worse. Overall, there was little difference between the two treatments.

The assessment of latent botrytis prior to marketing showed the Canopy TI treatment had 37% of leaf samples infected whereas the Normal TI treatment had 53% infected. This did not result in a significant difference in visible disease levels or shelf life.

3.3 Conclusions

3.3.1 Temperature integration

- TI is a reliable way of making energy savings. The saving achieved was 12%.
- In total three crops of Poinsettia (one in 2003, two in 2004) covering a total of 14,000 m² were grown using TI. All three crops produced plants that exceeded the required quality and shelf life specification.
- Good humidity control can be achieved when using TI.

3.3.2 Greenhouse environment measurement & control

- Conventionally positioned temperature and humidity sensors give a poor indication of the actual conditions experienced within the canopy of a Poinsettia crop grown on the floor.
- Measuring temperature and humidity within the crop canopy gives improved and more reliable humidity control. Using this method to control humidity in a commercial crop has been shown to give a significant reduction in latent botrytis.
- Simple temperature probes placed in the crop canopy are a cost effective means of providing additional information about the actual growing environment.
- Raising the crop off the floor will reduce the cooling effect of the floor in winter. This may allow a lower greenhouse temperature to be used, therefore saving energy.

4 Financial issues

4.1 Energy saving

The results of this project show energy savings of 16kWh/m². Based on a heating fuel price of 2.0 p/kWh this saving is worth 32p/m² (£3,200/Ha/crop). This is the saving only for a Poinsettia crop grown during the first half of the winter heating season. If a grower then grows an additional crop / crops at other times of the year, annual savings are likely to be around £6,500/Ha/year.

4.2 Crop performance

Based on scheduling, quality or shelf life there were no significant differences between the crop grown under the conventional and TI treatments in 2003. The same result was obtained with crops grown using different humidity control methods in 2004.

4.3 Cost of implementation

Growers with modern climate control computers may already have TI software installed. If so, no additional capital investment is required. Time will be required to implement and review new climate control settings and some training of staff may be needed .

Growers with older climate computers may require upgrades. This will depend on the age and capabilities of the system. Cost will range from approximately £5,000 /Ha for an upgrade to £15,000 /Ha for a new system. Based on a gross benefit of £6,400 /Ha, payback times of between one and three years can be expected.

It is possible to apply TI control principles to climate control computers that do not have specialist TI software built in. If this approach is taken then energy savings are also likely to be less and increased management time will be required.

Upgrading a climate control computer will bring other long-term benefits beyond those directly associated with TI. This can include factors such as better crop management. Such benefits should also be considered when assessing the payback on capital investment.

The cost of adding a simple temperature probe to a climate control computer will depend on individual site circumstances. Likely costs are £200 including supply, installation and software modifications.

5 Action points for growers

- Apply the principles of temperature integration. If an investment in a new / upgraded climate control computer is required, the pay back is likely to be less than 3 years.
- Ensure that key staff receive adequate training in greenhouse climate control.
- Check all measuring boxes weekly.
- Consider how the location of your measuring box relates to the actual conditions experienced by the crop. Relocate if necessary or install a second measuring box in a different location
- Install simple temperature probes as a low cost measure to provide additional insight into the growing environment.
- Compare compost temperature to the dew-point temperature of the air as a more accurate guide to the likelihood of condensation occurring.
- Keep tight control over the rate of temperature rise, aim for at least 20 minutes/°C. Particular focus is required during the period from sunrise to sunrise + 2 hours, even when the measured RH is low.
- If crops are grown on the floor measure the cooling effect of the floor on the canopy temperature. Consider the practical and cost implications of raising plants off the floor.

Science Section

6 Background

All protected horticultural businesses are under increasing pressure to reduce energy use:

- **Economics** – particularly rising costs from higher fuel prices.
- **Legislation and Taxation** – such as Climate Change Levy (CCL) and the associated energy saving agreements.
- **Consumer Pressures** – customer expectations relating to reduced environmental impact.

DEFRA statistics indicate that there is around 90 Ha of heated pot plant production in the UK. The total energy cost for this sub-sector is around £4.5 million/annum.

A study trip to Denmark and The Netherlands in 2001 (HDC project PC 172) concluded that the use of advanced greenhouse environmental control methods is an effective way of improving energy efficiency without compromising crop yield or quality. However some doubts remained regarding the level of savings that could be achieved and the limits on how far environmental control settings could be pushed without compromising crop quality. On this basis, HDC have supported a range of work to determine answers to some of these key questions.

Work has included a project carried out at HRI Efford (PC 190) which showed that temperature integration could be applied to a crop of pot Chrysanthemum with minimal effect on plant quality and scheduling. The energy savings in this work were as high as 25%. This work was replicated on a commercial nursery on the south coast of the UK over the 2002 - 2003 heating season (PC 197). Results showed energy savings to be 12% with no recorded effect on plant quality. PC 190 was also extended to study a crop of Poinsettia in 2002.

Despite this background of research, the principles of TI have still yet to be widely exploited commercially. The main reason for the low level of uptake seems to be that growers continue to lack confidence in the technique, especially the ability to control humidity.

This project was designed to build on the results of projects PC 190 and PC 197 and accelerate the uptake of temperature integration by further demonstrating its application on commercial ornamental nurseries growing a Poinsettia crop. The nursery participating in the trial was specifically chosen because of its northerly location and the heating and control facilities available at the site. Both were considered to contribute to a difficult humidity control situation which would stretch the likely limits for humidity control settings and subsequent energy savings.

7 Objectives

The objectives for the project were:

- To develop improved guidelines for measuring and controlling humidity in commercial greenhouses producing ornamental crops.
- Demonstrate that, when used in conjunction with advanced climate control strategies (e.g. temperature integration), improved humidity and disease control, and energy savings can be achieved.
- To promote an improved understanding of the fundamental principles applied when controlling humidity within a commercial greenhouse.
- Generate new information to be used to train protected crop growers in better greenhouse environmental control methods and energy management.

Taking 2004 in isolation, the specific objectives were:

- To demonstrate, for a second consecutive year, that a successful crop of Poinsettia could be grown using temperature integration strategies.
- To compare energy and crop performance from systems with TI using humidity sensing positions a) above the crop canopy and b) within the crop canopy.

8 Research method

The detail within this section relates specifically to the work carried out in 2004. For detail on the work carried out in 2003 refer to PC 207 Interim Report (June 2004).

8.1 Overview of location, facilities and cropping

As in 2003, the project was carried out at Coletta & Tyson Ltd, Millbeck Nursery, South Cave, East Yorkshire.

Two identical greenhouse blocks (Block A and Block B) were used for the work. Each of these blocks covers a ground area of 4,570 m². The greenhouses are of a Venlo design and were constructed approximately 30 years ago. Gutter height is approximately 3 m.

The greenhouses were originally built for cucumber production. Following the purchase of the site by Coletta & Tyson Ltd in 2002, modifications were made to make them suitable for ornamental crop production. This included moving the 'pipe rail' heating pipes to a mounting point on the greenhouse stanchions and laying black 'Mypex' material on the greenhouse floor.

The photograph below shows the general layout within each greenhouse.



No thermal, blackout or shade screens were installed in the house and CO₂ enrichment was not used.

The climate control computer at the site was a Priva Integro. This computer came with temperature integration (TI) facilities as a standard feature. In addition the ‘software sensor’ facilities were also available as a standard feature.

8.2 Data collection

The greenhouse environment and energy use data was recorded using the site climate control computer. Information was downloaded via modem connection at weekly intervals throughout the project. This was done remotely from the FEC office in Warwickshire. Data recorded included the following:

Weather data

- Outside temperature.
- Global radiation.

Greenhouse control and equipment data

- Set points – calculated heating & ventilation temperature.
- Heating system – calculated & measured heating pipe temperatures.
- Ventilation system – measured vent position.

Energy use

- Heat meters were installed in each heating circuit. This enabled energy use to be accurately determined.

Crop data

- Routine measurements relating to crop development (height) were taken by nursery staff.
- Graphical tracking of crop development was carried out using the HDC Poinsettia Tracker™ software.
- Plant quality was formally assessed at the time of marketing by Fay Richardson & Jonathan Dearlove of Coletta and Tyson.
- Shelf life assessment was carried out at HRI Kirton.

Greenhouse environmental data

Table 1 below lists the measurements taken and the recorded / calculated data derived from each piece of instrumentation.

Table 1 – Greenhouse environmental data recorded

	Temperature °C	Relative Humidity %	Dew-point temperature °C
<i>Normal</i> Measuring Box (30 cm above crop canopy)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Canopy</i> measuring Box (sampling from within the crop canopy)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Infra-red</i> camera (canopy surface temperature)	<input type="checkbox"/>		
<i>Canopy probe</i> (simple temperature probe within the crop canopy)	<input type="checkbox"/>		
<i>Compost</i> (core compost temperature)	<input type="checkbox"/>		
<i>Ground</i> (temperature of the earth the pots are placed on)	<input type="checkbox"/>		

8.3 Treatments

Both treatments used temperature integration. The same set points were applied in both treatments. This included:

- Heating temperature strategy.
- Ventilation temperature strategy.
- Minimum pipe temperature.
- All influences applied to the above e.g. humidity & radiation.

The key difference between treatments was the humidity measurement position used as the basis for humidity control.

- One treatment used the relative humidity measured just above the crop canopy. (*Normal*)
- The other treatment used the relative humidity measured by sampling air from within the crop canopy. (*Canopy*)

Target humidity level

In both treatments, the following 'rules' were applied:

- Target RH - below 90%.
- Brief periods >90% allowed but must be brought under control within 30 minutes.

These rules were applied irrespective of the time of day.

Target average greenhouse temperature

The target average temperature was adjusted according to the requirements of the crop i.e. stage of growth & height. Unless significant differences between the crops were observed the same target average temperature was used in both treatments.

The temperature in both treatments was controlled using the temperature measured just above the crop canopy. (*Normal*)

Temperature Integration

The TI settings were regularly reviewed and modified where necessary to:

- Achieve the required target average temperature.
- Achieve RH control as defined in the previous section.

The operating ranges allowed were as follows:

- The daytime heating temperature was the same as that used in a conventional temperature control regime i.e. no reduction due to TI was allowed.

- TI was allowed to reduce the greenhouse temperature to a minimum of 15°C during the period from 1 hour before sunset to the start of the Drop period.
- Ventilation temperature was set to a maximum of 26°C when the RH. was <75% to allow the accumulation of degree-hours for use during the night-time.
- The integrating period was 7 days.

8.4 Climate control

Crop & climate control diary

Table 2 below gives an overview of the significant events in the 2004 cropping season. These applied to both treatments.

Table 2 – Climate control diary (2004)

Week	Notes
29 & 30	Cuttings potted.
36	Plants moved from rooting to trial greenhouse compartments. Temperature integration applied in both treatments. Drop applied to aid height control in both treatments. Active humidity control required during the night-time from now onwards. Maximum ventilation temperature limited to 19°C, to help keep the average greenhouse temperature down. Night-time heating temperature consistently 15°C.
38	Maximum ventilation temperature increased to 25°C as weather deteriorates to help accumulate degree-hours.
40	Degree-hours becoming more limited. Minimum night-time heating temperature increased to 16°C to help spread degree-hours from one 'good' day over 2 – 3 nights.
42	Minimum night-time heating temperature increased to 17°C.
44	Continually deteriorating weather conditions meant that heat demand for temperature control adequately controlled RH by default. Therefore no active RH control was required from this week onwards.
46	Virtually no degree-hours accumulated due to deteriorating weather. Therefore temperature integration turned off. Minimal venting required, only during the Drop period.
47	Drop period removed, no venting required at all.
50	Crop sold.

Climate control strategy

The following describes the basic approach to climate control (both temperature and humidity) in both treatments. The only difference between treatments was the position of humidity measurement used for climate control.

The absolute values of the set points, particularly heating and ventilation temperatures are indicative only. Those applied in practice were varied according to crop requirements.

Key features were:

- The heating temperature was always higher during the day than at night.
- The Drop period temperature was ramped down to be at the target temperature 30 minutes before dawn.
- Following the end of the Drop period the temperature was allowed to rise slowly to the day temperature (20 minutes/°C). This was to avoid rapid rises in temperature that might ultimately cause condensation on cold plants or pots.
- At the end of the daytime period the temperature was reduced at a rate of 30 minutes/°C. This was to allow the temperature to fall naturally through heat loss rather than through unnecessary venting.
- As long as the RH was at an acceptable level, the ventilation temperature was kept 1°C higher than the heating temperature.

Figure 6 – Typical heat & vent strategy (2004)

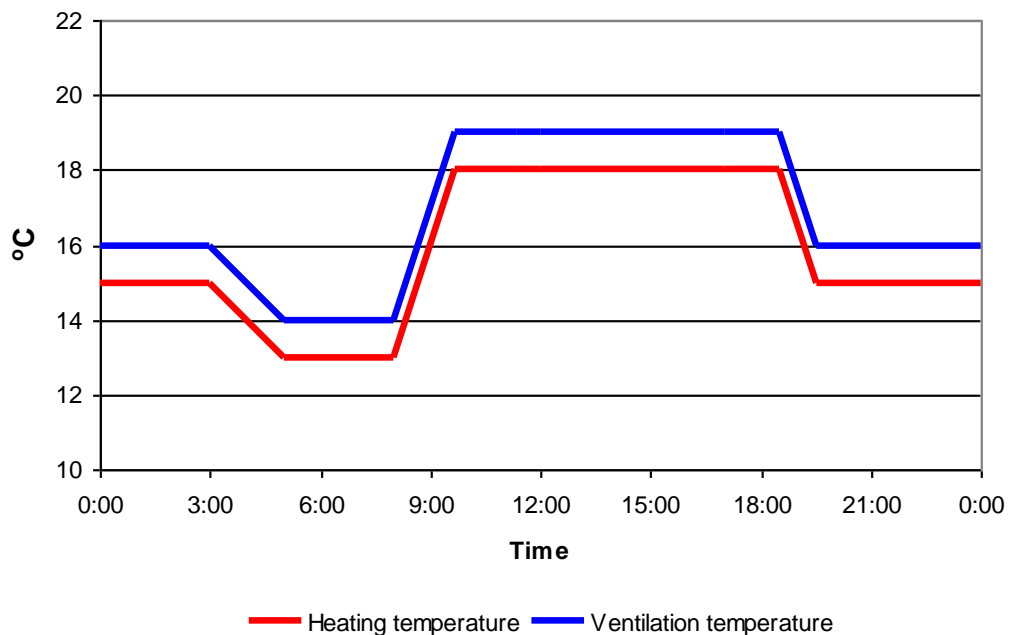


Figure 6 shows a heating temperature during the night equal to the minimum allowed (15°C). This only occurred when sufficient spare degree-hours had been accumulated. It should be noted that the graph does not show any increase or decrease in ventilation temperature due to humidity influences.

Humidity control

The settings used to control humidity were chosen based on a ‘vent then heat’ approach rather than the more conventional ‘heat then vent’ used by many growers. In practice a true ‘vent then heat’ approach is not possible but the underlying principles can be applied to achieve energy savings.

Coletta & Tyson’s Technical Manager and the Site Manager set the following humidity control target:

- An RH of 85% or less is ideal.
- A steady RH of up to 88% is acceptable.
- As the RH rises above 85% humidity control settings should start to take effect.
- The RH should only exceed 90% for short periods – typically less than 30 minutes.

The set points used were modified to achieve the required level of control with fine-tuning, as the crop developed. The same humidity control settings were applied to both treatments. From week 38 onwards they remained unchanged.

The settings used from week 38 onwards are detailed below.

Pump On / Off control

Pump control remained at the default settings of:

- Pump On if the calculated pipe temperature was more than 5°C above the greenhouse temperature.
- Pump Off if the calculated pipe temperature was less than 3°C above the greenhouse temperature.

Minimum pipe temperature

The basic minimum pipe setting was 10°C. This was to ensure that the pump turned off whenever heat was not required. Humidity influences were then applied as detailed in Table 3 below.

Table 3 – Minimum pipe humidity influences

RH %	Increase in MP °C	Resulting minimum pipe set point °C
80	0	10
85	5	15
90	12	22
95	20	30

A minimum pipe temperature of 22°C may seem to be very low. In practice, as soon as the pump turned on, a pipe temperature of 30 - 35°C was delivered. This was because the mixing valve did not fully close. As a result the settings described above were essentially used as a means of humidity related pump control.

Ventilation temperature

The basic heating and ventilation strategy, excluding any influences, was set to give a ventilation temperature 1°C above the heating temperature. Humidity influences as detailed in Table 4 below were applied.

Table 4 – Ventilation temperature humidity influences

RH %	Influence on ventilation temperature °C	Resulting heat – vent differential °C
* 75	+3.0	4.0
85	0	1.0
90	-0.5	0.5
95	-1.0	0

* - This influence formed part of the TI strategy and was used to help accumulate degree-hours when the humidity conditions in the greenhouse were considered to be safe. The amount by which the ventilation temperature was increased was determined by the average temperature achieved. For example, if the weather was consistently good and temperature integration was unable to use all the available degree-hours, the average greenhouse temperature would be too high. Therefore the humidity influence on ventilation temperature was reduced. As weather conditions deteriorated the humidity influence was increased to help accumulate as many degree-hours as possible.

8.5 Greenhouse environmental data

Temperature

All of the data in this section relates to the temperature measured by the conventionally positioned measuring box. (*Normal*)

Figure 7 below shows the average temperature in each treatment on a week by week basis. Over the complete production period (week 36 - week 49) the average temperature in both treatments was 19.4°C.

The average temperature was almost identical throughout the trial. The increase around week 47 was due to the removal of the drop period.

Figure 7 – Average 24-hour temperature

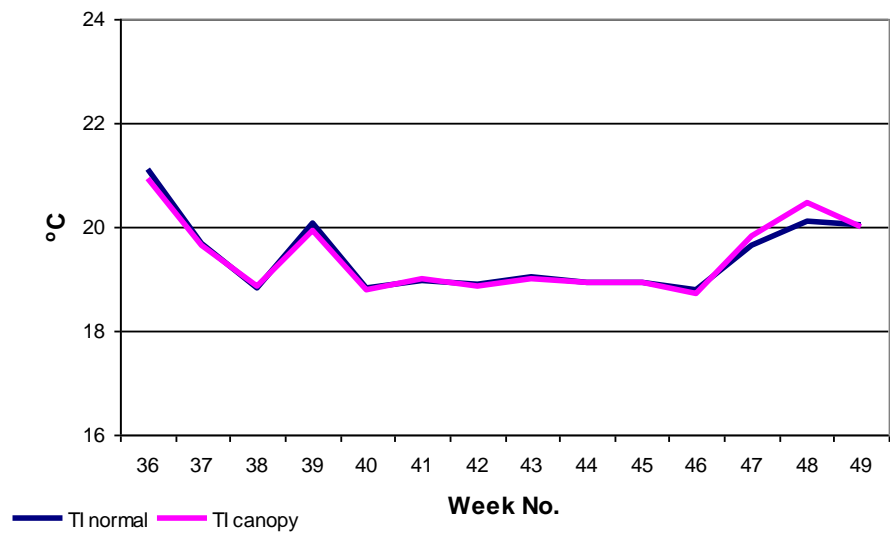
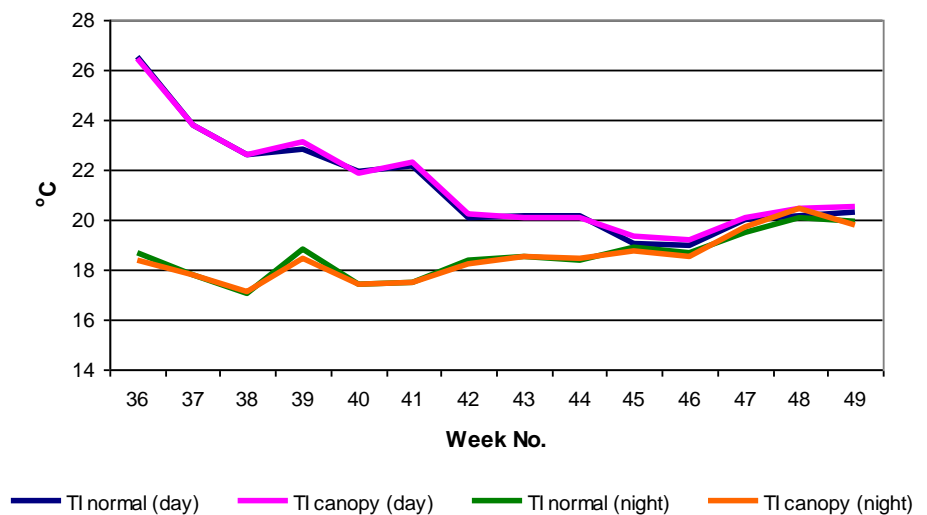


Figure 8 – Average day / night temperature

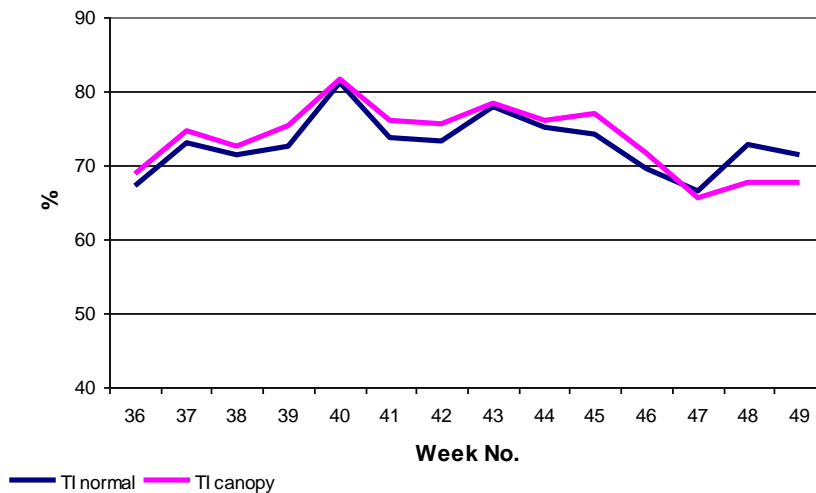


Like 24-hour average temperature, the average day & night temperatures show little difference between the TI_{normal} and TI_{canopy} treatments. It is worth noting that although a night-time heating temperature of $15^{\circ}C$ was set during weeks 36 – 39, the lowest average night-time temperature during this period was in fact $17^{\circ}C$. This happened because of the carry over of warm air from the day into the night, higher outside temperatures and a slight heating effect from the warm floor of the greenhouse.

Relative Humidity above the crop canopy

All of the data in this section relates to conditions measured by the conventionally positioned measuring box. (*Normal*)

Figure 9 – Average RH



The trend between weeks 36 – 47 shows TI_{normal} to have a lower average RH than TI_{canopy} . On average the difference was 1.8%. Bearing in mind the positions used to sample the air for humidity control in each treatment, the opposite would have been expected as a result of more active and prolonged humidity control in the TI_{canopy} treatment.

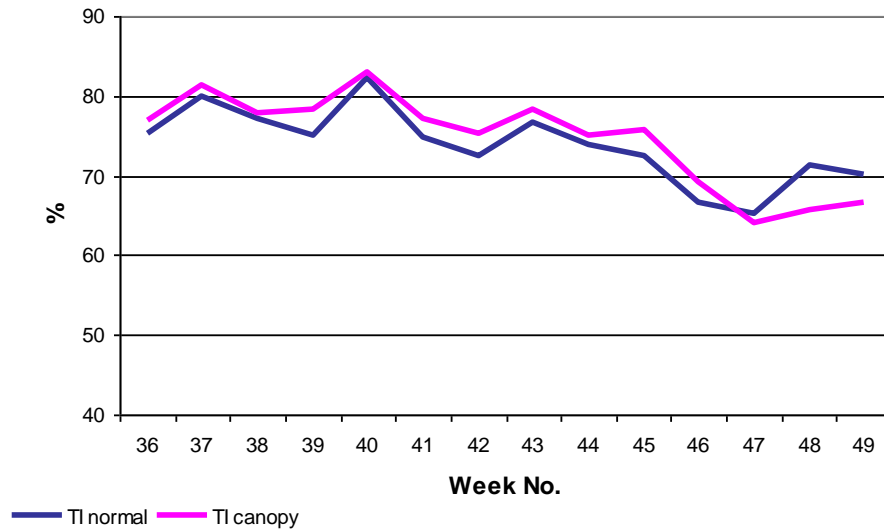
During weeks 48 & 49 the RH in the TI_{canopy} treatment was significantly lower than in TI_{normal} . This was due to the intermittent failure of a measuring box towards the end of week 48 and into week 49 which caused some unnecessary venting to control humidity.

In the case of the night-time average RH (Figure 10 below) a similar trend is evident. The difference averaged 1.9% between weeks 36 & 47.

Taking into account the accuracy of humidity measurement and the unavoidable physical differences between greenhouses and their heating and ventilation systems (even when they

are theoretically identical), an average difference in measured relative humidity of less than 2% is acceptable.

**Figure 10 –
Average
night RH**



Relative humidity control– above canopy compared to within canopy

The difference between the two treatments in this project was the position of the RH measurement used by the greenhouse climate control computer for environmental control.

RH measurements were taken at the two positions for each treatment. These were:

- Just above the canopy – *Normal*.
- Within the canopy – *Canopy*.

Weeks 36 - 37

As expected, differences between the two measurements only occurred once the crop canopy was reasonably developed and air exchange between the canopy and the air above it became more restricted. In addition smaller plants add less water to the atmosphere and the need for active humidity control early in the development of the crop was therefore minimal in both crops.

For the first two weeks (36 & 37) there was little difference between the two measurements and therefore between the two treatments.

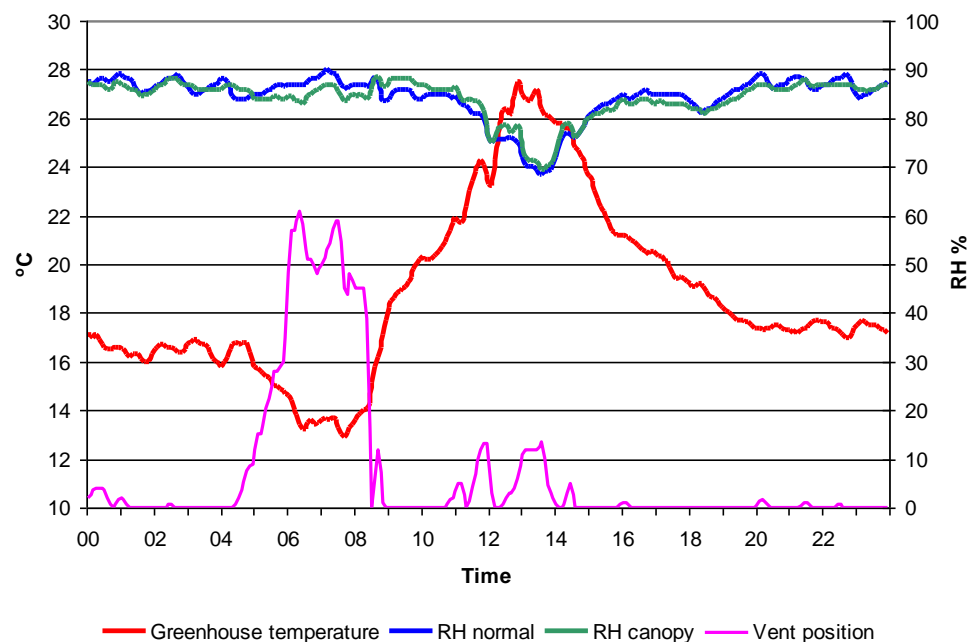
Weeks 38 – 40

Figure 8 overleaf shows a typical day in week 40, the general trends are the same for both treatments.

Between 00:00 and 04:00 the two humidity measurements were similar, albeit with some damping evident within the canopy. Shortly after 04:00 the drop period started, the vents opened to reduce the greenhouse temperature with no minimum pipe temperature in use. The humidity above the canopy increased as cold, high humidity air came into the greenhouse from outside. However the humidity within the canopy actually fell. At this point the floor temperature was around 19°C and the crop (plant, pots & compost) was around 17-18°C, whereas the greenhouse temperature was less than 14°C. The result was that the residual heat within the crop canopy heated the colder greenhouse air as it penetrated the crop canopy and reduced its RH. Once the greenhouse temperature was allowed to rise, heating dominated by solar gain caused the RH above the crop canopy to reduce. Although the RH of the air within the canopy fell slightly it remained higher until the vents opened to more than 10% for a brief period around 12:00. Once the vents closed, the canopy RH rose, even though the RH above the canopy remained stable. It only fell to the same level once the vents opened again.

This is a good indication that the relative position of the crop and heating system was not promoting good air movement within the canopy. It should be noted that horizontal air mixing fans were used in the trial greenhouses. Opening the vents is clearly the most effective way of ensuring good air movement within a crop in these circumstances.

**Figure 11 – A
typical day in
week 40**



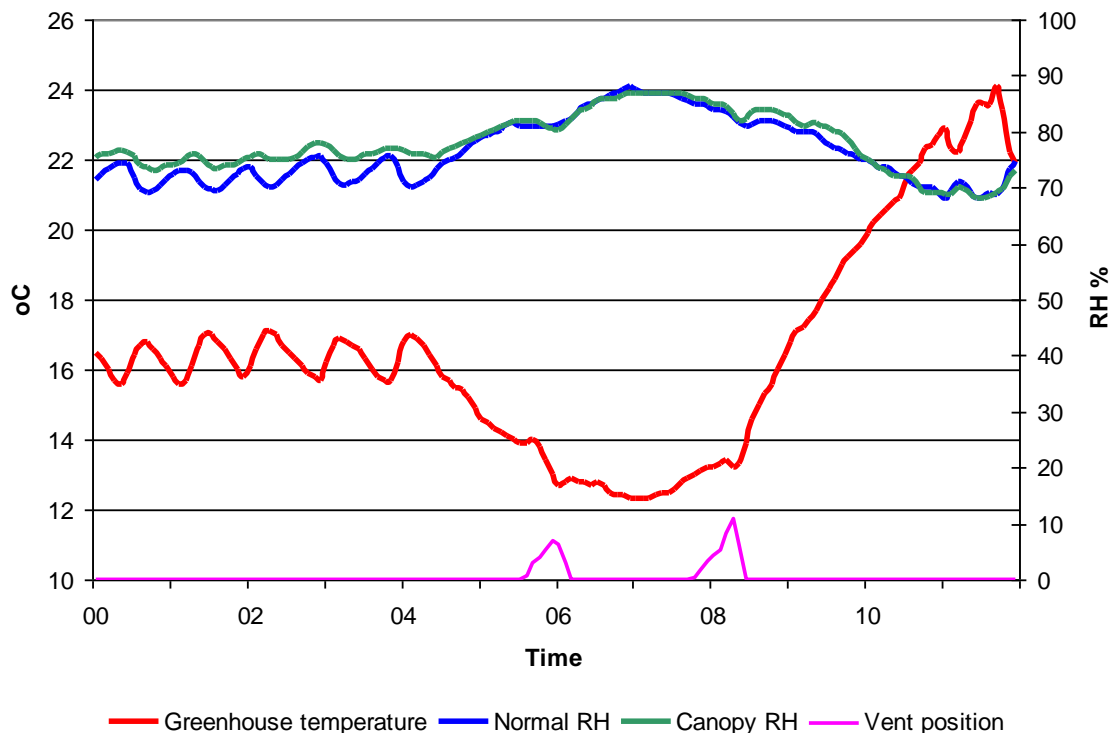
Weeks 41 - 44

Figure 12 overleaf focuses on the first half of the day and allows more detail to be seen. Up until 05:00 the greenhouse temperature varied cyclically around the set point of 16°C. Although this level of variation was more than ideal this was symptomatic of the heating system on site and not the control system or set points being applied. It also illustrated the damping or smoothing effect of poor air circulation between the crop canopy and the area above it. This is reflected in the variation in *normal* RH compared to the *canopy* RH which varied in the same cyclical way but at a much reduced amplitude. On average the *canopy* RH was 4% higher than the *normal* RH up to 04:00.

From 04:00 to 08:00 the drop period applied. This required minimal venting and virtually no heat input during this period. With little air movement influence from heating or venting, the RH had time to evenly distribute itself between above and within the canopy. As the greenhouse temperature rose after 08:00 the difference in RH grew once again. A brief but small amount of vent (<10%) reduced the differential slightly but was not enough to have a significant effect.

A further factor to consider during this period was the reduced ground temperature, around 18°C and compost temperature at 17°C. The benefit from the residual heat in the ground and the compost, heating the air and helping to control humidity within the canopy, (as described during weeks 38 – 40) was much reduced.

Figure 12 – A typical morning in week 42



Weeks 45 - 50

During this final stage of the project the ripple effect on humidity and the difference in humidity levels measured between the two locations, between 00:00 and 04:00 happened virtually all the time.(Figure 12). This was due to the constant heat demand and no venting.

Where did the main differences occur?

So far the characteristics of the humidity measured both above and within the canopy appear to be similar for both treatments. However focusing on the key parts of the day when humidity control was required revealed some differences. The times in question are:

- Night-time humidity control.
- Humidity control following the drop period.

The need for humidity control during the night-time was at it greatest during weeks 38 – 40. This coincided with a thin crop canopy and the warming effect of the ground. The result showed little difference between the two humidity measurements and therefore little difference between treatments.

Humidity control immediately following the drop period was still required when the crop canopy was fully developed. Figure 13 & Figure 14 overleaf focus on this period for one day in particular to demonstrate the effect of using a different humidity measurement to influence the ventilation temperature.

Taking the *Normal* situation first (Figure 13), both RH measurements were similar (90%) until around 09:00. At this point the set heating and vent temperatures slowly increased and the *Normal* RH reduced to less than 75%. As the humidity influence on ventilation temperature used the *Normal* RH measurement the difference between heat & vent set points was allowed to increase because the RH was considered to be ‘safe’. Venting to help control humidity and improve air movement stopped at around 09:30. However due to the fully developed canopy, the *Canopy* RH remained high for much longer and only fell to 85%.

Compare this to Figure 14 overleaf where the *Canopy* RH is used to influence the ventilation temperature. As the *Canopy* RH remained high for longer the difference between heat & vent set points remained smaller. This meant that venting continued up until almost 10:00 and even started again at around 11:20.

Figure 13 – Humidity during the drop period (TI_{normal})

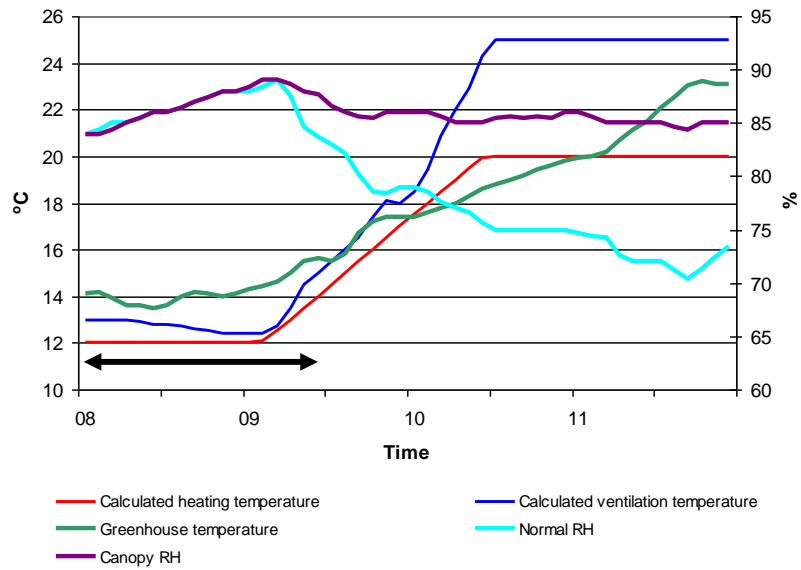


Figure 14 – Humidity during the drop period (TI_{canopy})

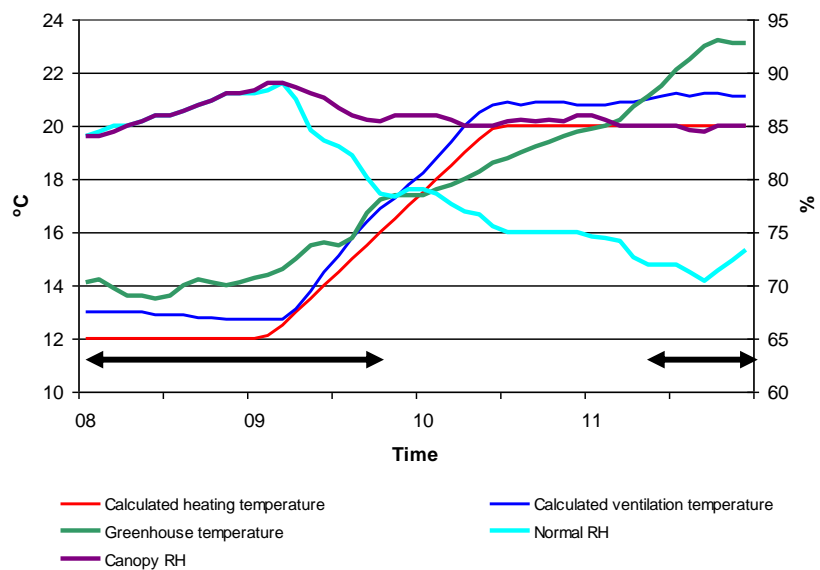
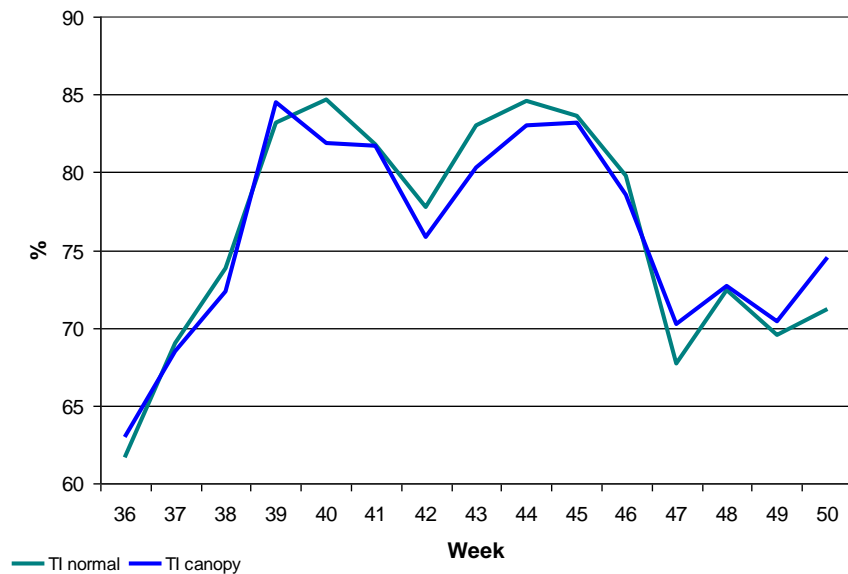


Figure 15 overleaf shows the average RH measured within the crop canopy during the period from 1→3 hours after sunrise. It shows that once the crop canopy became more developed (week 40), the RH within the canopy remained consistently lower during this critical part of the day when condensation on the crop was most likely. The difference continued until week 45 when high heat supplies to maintain the greenhouse temperature helped to encourage air movement. Finally the drop period was removed towards the end of week 46. During the last few weeks the canopy RH in the TI_{normal} treatment is actually higher than in the control. However, at this stage the RH was low and the risk of condensation on the crop was minimal.

**Figure 15 –
Average canopy
RH (early
morning)**



It should be noted that relying on a vent-then-heat approach to humidity control meant that additional heat in the form of an increase in minimum pipe temperature was rarely required. Improved humidity control was achieved within the crop canopy through venting which delivered improved air movement and therefore moisture exchange between the dryer air above the canopy and that trapped within it.

Normal, Compost & Ground temperature

Figure 16 overleaf shows the average weekly *normal* (greenhouse) temperature measured at various locations. Although not directly related to temperature integration or humidity control the trends were interesting when considering a crop grown on the ground.

Comparing the *Ground* to *Normal* shows the *Ground* to be 1.5°C higher during the first three weeks. The effect was to heat the compost in the pots and produce an average *Compost* temperature above that of the air (*Normal*).

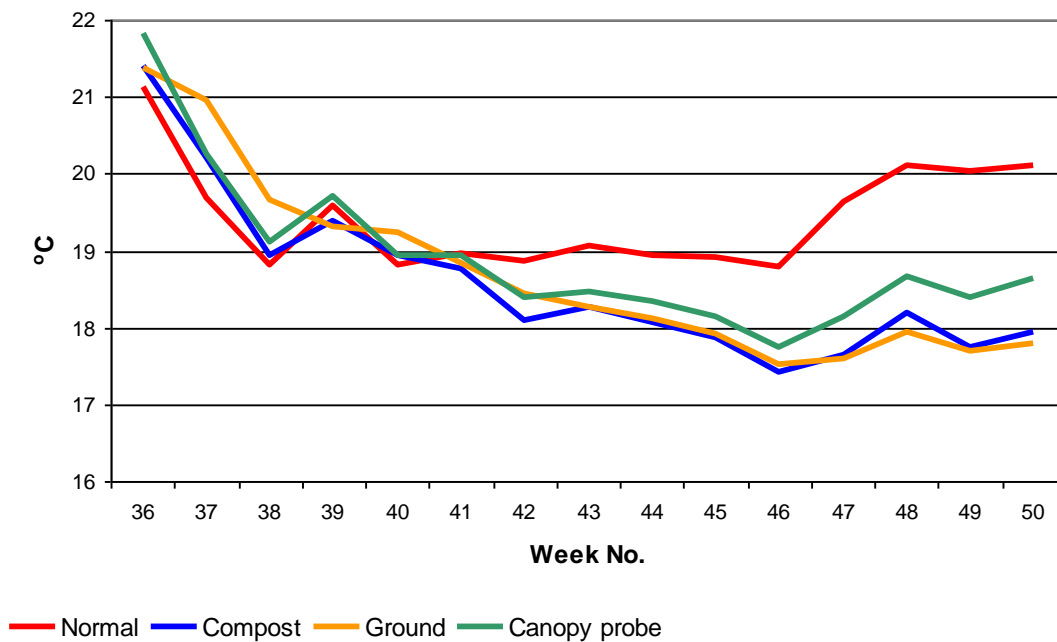
As weather conditions deteriorated and the temperature of the earth in general fell, so did that of the *Ground*. This happened to such an extent that by week 50 the ground temperature was around 18°C. This cooled the compost in the pots and the *compost* temperature was only slightly warmer than the *ground* itself even though the *normal* temperature was 2°C higher. An additional factor affecting the *compost* temperature was the unheated irrigation water. This came directly from a borehole. Although its temperature was not measured, it was expected to be less than 10°C.

The combined effect of the cold ground, cold irrigation water and evaporative cooling from transpiration was that from weeks 41→50 the air temperature within the crop canopy was 18.4°C compared to an average *Normal* temperature of 19.3°C.

Considering how a crop grown on benches might differ, it would be reasonable to expect the *Compost* and *Canopy* temperatures to be:

- Lower during weeks 36 – 39 when keeping average temperatures down is generally important.
- Higher during weeks 40 – 50 when energy use is high. Possibly allowing a lower greenhouse temperature to be used and therefore saving energy.

Figure 16 – Average weekly temperature (simple probes)



Energy

The total amount of energy used (as gas) between weeks 36 – 49 was:

- TI_{normal} 136 kWh/m².
- TI_{canopy} 134 kWh/m².

This suggests that controlling humidity according to the *Canopy* RH saved 2 kWh/m² (1.5%). Logic would suggest that more energy should have been used.

Exploring this further an explanation is possible. Early in the trial the canopy was not fully developed and differences between the two humidity measurements were small and therefore had little effect on energy use. In addition, humidity control was achieved mainly by venting with the heating effect of the ground providing part of the energy required.

Once a full crop canopy had developed and the heating effect of the ground reduced, the need for active humidity control reduced apart from the time immediately after the drop

period. In this case, humidity control was achieved by venting with the majority of the energy input provided by solar gain.

Finally, humidity control from week 44 onwards was achieved by default due to the continuously high heat demand required for greenhouse temperature control. Taking all these points into consideration the fact that there was little difference in energy use does appear possible.

8.6 Crop data

Production diary

- Potting dates week 29 and week 30.
- Variety – Sonora.
- Plants transferred into final growing on (trial) area – week 34.
- Marketing – week 50.

Crop spacing dates and growth regulator applications were the same in both treatments and according to standard commercial practice.

Height tracker

Crop development (height) was tracked against target using the HDC Poinsettia Tracker™ software. Figure 14 – Figure 16 overleaf shows the measured height against track for week 29 (cutting batches C & H) and week 30 (cutting batch C).

Week 29 C potting

Both treatments started at virtually identical heights. As time progressed the TI_{normal} crop tended to be slightly taller but the difference was minimal. Both were within the height specification required by the customer.

Week 29 H potting

Both treatments started at virtually identical heights. Unlike the week 29 C potting, as time progressed the TI_{canopy} crop tended to be slightly taller and the difference was greater than the week 29 C potting. Both were within the height specification required by the customer.

Week 30 C potting

From the point of arriving in the trial greenhouse (week 37) the TI_{canopy} plants were always taller than the TI_{normal} . The difference in height increased slightly as the trial progressed, albeit by a small amount. This was the opposite to what happened with the week 29 H potting in spite of the fact that the week 29 and 30 pottings were grown in the same

greenhouse for each treatment and therefore experienced the same environmental conditions.

On average, there was no significant trend to suggest a difference in plant height due to the different treatments.

Figure 17 – Height track (week 29, C)

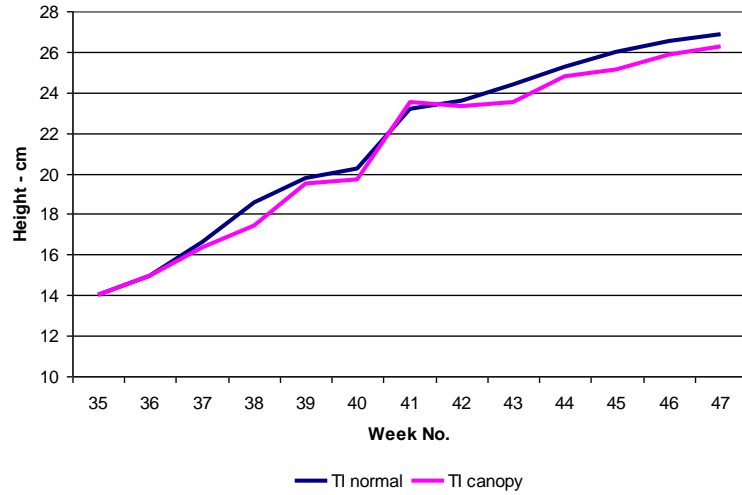


Figure 18 – Height track (week 29, H)

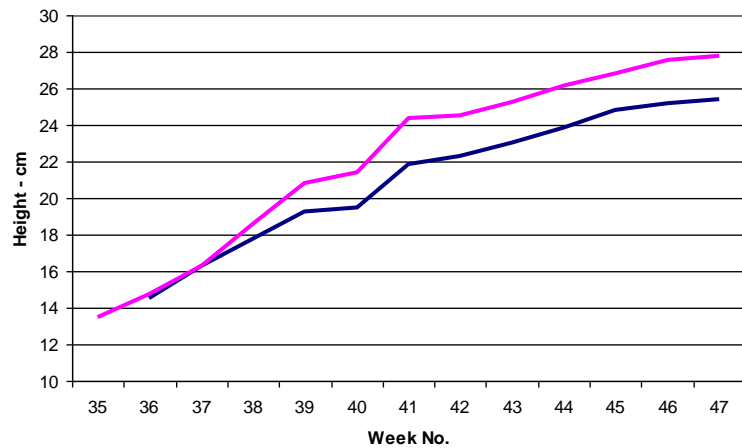
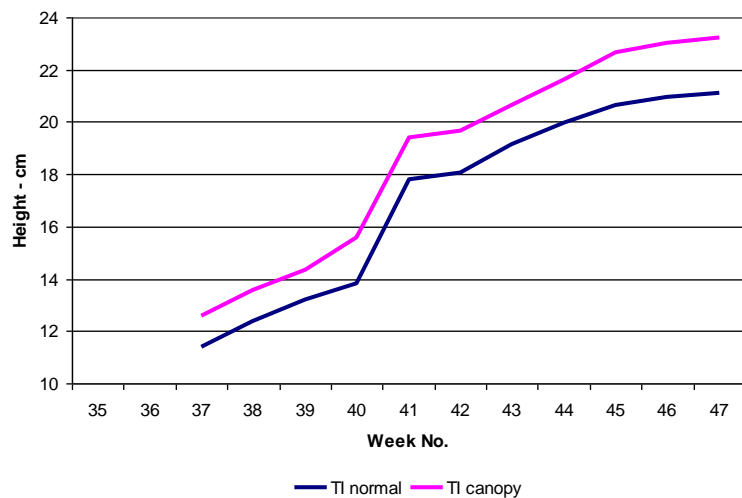


Figure 19 – Height track (week 30, C)



Assessment prior to marketing

The crop assessment was carried out by Fay Richardson, Coletta & Tyson Technical Manager. A total of 20 plants from each treatment were assessed according to the assessment protocols used in the HDC annual variety trials.

Adjustments to marketing plans made by the customers meant that it was only possible to carry out this assessment on the crop potted on week 29 from cutting batch C. A summary of the findings is given in Table 5 below.

Table 5 – Plant quality assessment

	Height cm	Width cm	No. main bracts	No. secondary bracts	Cyathia stage	Leaf drop
TI _{normal}	27.3	45.3 x 45.3	5	2.5	2.5	2
TI _{canopy}	28.9	44.9 x 44.9	5.35	2.25	2.15	2.4

Summary

The width of the plants was slightly bigger in the TI_{normal} treatment but the difference was small (1.6 cm) and had no impact on sleeveability. There were slightly more primary bracts and fewer secondary bracts in the TI_{canopy} crop and the stage of development of the cyathia was slightly behind. Leaf drop was greater but of little immediate consequence at this stage.

The difference in plant height as shown in Figure 14 (page 30) remained up until marketing. This had no apparent effect on the other quality assessments.

Overall, there was little difference between the two crops and both were of a marketable standard with the same final grade out figures.

Shelf life test

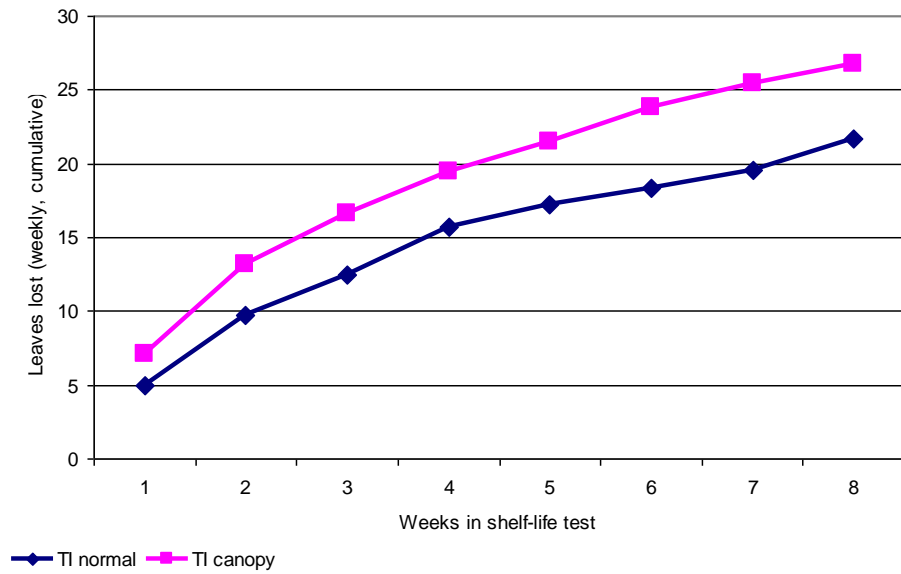
Test protocol

Shelf life tests were carried out in the same way as in 2003.

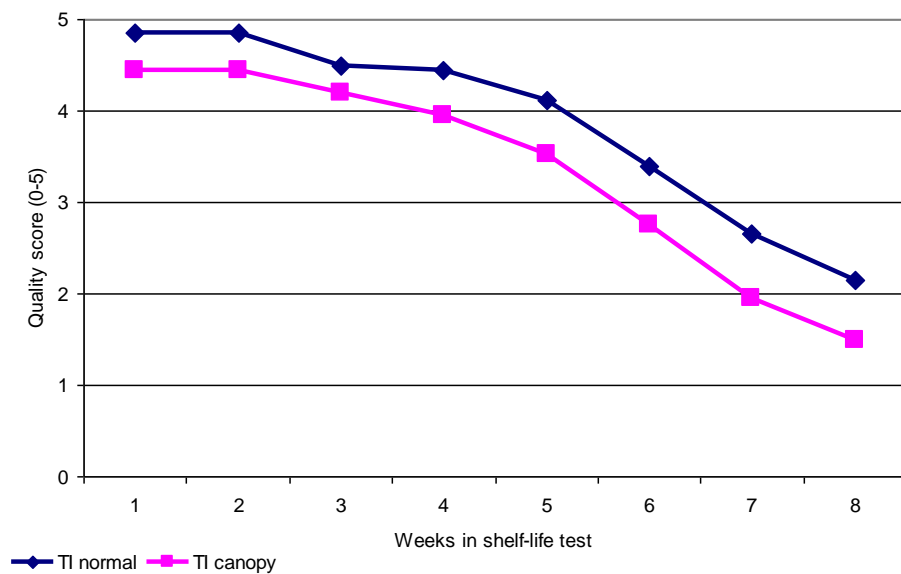
Results

Figures 17 & 18 overleaf show two of the main shelf life criteria.

**Figure 20 – Shelf
life leaf loss**



**Figure 21 – Shelf
life quality score**



Total numbers of leaves lost in the TI_{canopy} crop was consistently higher throughout the shelf life testing period. The majority of the difference occurred during the first two weeks of shelf life testing when the TI_{canopy} crop had lost 4.2 leaves more per plant than TI_{normal} . The final figures after eight weeks showed a difference of 5.1 leaves per plant. A similar trend was apparent in the bract loss. These differences were reflected in overall quality score.

Although the overall quality score for the TI_{canopy} crop was consistently lower than TI_{normal} it should be noted that a score of 5 is the maximum possible. After one week the TI_{normal}

crop scored 4.85 and the TI_{canopy} crop 4.45. Therefore albeit of a slightly lower overall quality, the TI_{canopy} crop was still of a high quality.

The shelf life assessment carried out considered that once a plant had an overall quality score of less than 1 it was 'dead'. On this basis both the treated and control crops achieved an average shelf life in excess of eight weeks.

Botrytis assessment

A detailed assessment of botrytis during production, at marketing and during shelf life was carried out by Dr Tim O'Neil of ADAS Consulting Ltd. A complete version of his report is included in Appendix 1. A summary of his findings follow.

Latent botrytis

A low level of latent botrytis (5% of lower leaves affected) was detected on plants in both treatments at the start of the experiment (week 36). There was no difference between the two blocks. Eleven weeks later, the incidence had increased to 52.5% in the TI_{normal} and 36.7% in the TI_{canopy} crop. No sporulating botrytis or lesions were visible on leaves at this time.

Visible botrytis

No visible botrytis was observed in week 36, one week after plants were placed in the house. One wilting plant with severe *Pythium* root rot was found in the TI_{canopy} crop. The roots of other plants appeared white and healthy. There were occasional dead leaves on the pot surface, but no sporulating botrytis was present.

When examined on 28 November (week 48), just prior to dispatch, sporulating botrytis was present on detached necrotic leaves on the pot surface of around 60% of plants. There was no significant difference between treatments. A small number of plants (2.5% in the TI_{normal}, 0.8% in TI_{canopy} crop) had sporulating botrytis on one lower attached necrotic leaf. All of the plants inspected were marketable. No powdery mildew or other foliar or stem diseases were observed.

Development of botrytis in shelf-life tests

Very low levels of botrytis were visible after one week, as sporulation on necrotic fallen leaves. There was significantly less on plants from the TI_{canopy} treatment than in the TI_{normal} treatment. After three weeks, botrytis levels were still very low and there was no difference between treatments. No bract spotting or botrytis lesions developed on plants. Most leaves from the lower third to half of the plants had fallen after three weeks, with little difference between the treatments.

Conclusions and discussion

Latent botrytis was detected in, or on, lower green leaves at a low incidence (5%) shortly after the plants were placed in the greenhouse blocks.

Eleven weeks later, this had increased considerably. There was a significantly greater percentage of plants with latent botrytis in the TI_{normal} crop (53%) than TI_{canopy} crop (37%). This may reflect a greater frequency of long-duration high humidity periods during the immediate post-drop period as highlighted in Figure 12 (page 27).

No sporulating botrytis or lesions were observed on green leaves during crop production. Sporulating botrytis was observed only on dead leaves, and these were usually detached and on a wet compost surface.

No bract spotting or botrytis lesions were observed on plants during three weeks in a shelf-life room.

Occurrence of latent botrytis at a high incidence on the lower leaves of plants during crop production does not necessarily indicate that a botrytis problem will develop post-dispatch. It is possible that there may be a greater risk with such plants, especially if botrytis sporulation occurs at the crop base, and spores released from them contaminate upper leaves and bracts, and these subsequently develop to infect leaves (e.g. if condensation occurs during transport of plants). However, if botrytis-contaminated leaves fall onto the compost surface and dry-up they pose little risk. If they are trapped in the plant canopy, they will pose a greater risk. Removal of necrotic leaves, as usually done prior to sleeving and dispatch, should reduce the risk of subsequent botrytis development by contact spread from infected necrotic leaves.

9 Discussion

9.1 Energy

The TI_{canopy} treatment used 1.5% more energy than the TI_{normal} treatment. On face value, the opposite would have been expected. Closer investigation showed that in the specific circumstances of this trial the different humidity control measurement only had a significant impact between the end of the drop period and 2 – 4 hours afterwards. By adopting a vent then heat approach to humidity control this meant that the majority of any heat requirement was provided by solar gain and therefore the impact on energy use was small. As only 1.5% less energy was used, the difference between treatments is considered to be insignificant.

9.2 Humidity & temperature measurement

It is clear that the conventional location of a measuring box (*Normal*) is far from ideal, as it does not truly represent the conditions experienced by the crop.

The second measuring box (*Canopy*), which was configured to draw air from within the crop canopy, was shown to give a better indication of the conditions experienced by the crop. However, significant differences only occurred once the crop canopy was fully developed and air exchange between the canopy and air above it became restricted. Comparing the calculated crop environment (Priva ‘software sensors’, *Plant* and *Top of Plant*) to true readings (from the *Canopy* measuring box, *Canopy Probes* and *Infra-red* camera) gave mixed correlation. Although not as accurate as measuring the conditions directly, controlling according to the calculated plant humidity, especially during the critical period immediately after the end of the drop period, could help to control condensation events.

The temperature measured by the *Infra-red* camera was initially affected by the incomplete crop canopy. This meant that the temperature measured was a combination of floor, pot and plant. During this period the calculated plant temperature was consistently higher and spot readings of individual leaves in direct sunlight were in closer agreement to the calculated figure. However, spot readings also showed that even adjacent leaves (one in direct light and the other not) were at significantly different temperatures. The best and most consistent comparison between calculated *Top of Plant* and *Infra-red* temperature was during the night when both showed the canopy surface temperature to be 0.5 → 1.0°C below the air temperature as measured at the conventional measuring box location. At a RH of 90% the dew point temperature of the air is 1.3°C below the actual air temperature. Therefore if the measured canopy surface temperature can be as much as 1.0°C below the measured air temperature it is only 0.3°C above the dew point temperature of the air above it and the risk of a condensation event is therefore very high. This confirms, from a measurement and

control point of view, ornamental growers rule of thumb that only short periods at 90% RH are considered acceptable.

The calculated *Plant* temperature, which takes account of the thermal inertia of the plant, showed good agreement with the simple temperature *Canopy Probes* during the critical morning warm up period. However, this was only after software tuning had taken place using information gained from the *Canopy Probes*. This begs the question as to how a grower using a software-sensor knows whether it is configured correctly if there are no direct measurements to compare with. The calculated *Plant* temperature also feeds back to the calculated *Plant* humidity so the accuracy of the latter relies on the accuracy of the former.

Once the crop canopy was fully developed there was good agreement between the measured *Canopy* RH and calculated *Top of Plant* RH during the night-time period. This was not the case during the day. However, this tended to be at higher light levels when high RH was not a problem.

The most notable and potentially interesting difference between the various direct temperature measurements was from week 42 onwards. Here the average temperature of the *Ground* fell below that of the greenhouse air temperature measured above the crop (*Normal*). Between weeks 48 & 50 the *Normal* temperature was around 20°C and the *Ground* temperature was just under 18°C. The low *Ground* temperature tended to cool the compost and the two tracked each other quite closely.

Most significantly, the temperature within the crop canopy was 18.5°C. This suggests that it may be possible to produce the same crop at a lower greenhouse temperature by raising it off the floor. Furthermore raising the crop off the floor using perforated benching should improve air movement within the crop canopy and therefore give improved disease control or allow a relaxation of humidity control set points.

9.3 Crop quality

Crop quality, disease and shelf life assessments produced some conflicting results.

Crop quality at marketing showed no significant difference between the two treatments. Shelf life testing showed the TI_{normal} treatment to be better, although the quality of the TI_{canopy} crop was still good.

Assessment of latent botrytis levels showed there to be significantly less in the TI_{canopy} crop (37%) compared to TI_{normal} (53%). Levels of botrytis on fallen leaves during the first three weeks of shelf life testing were also less but from week 4 onwards there was little difference. Overall botrytis levels during shelf life testing were low in both treatments.

During shelf life testing the overall quality score for the TI_{canopy} crop was consistently lower albeit still of a good standard. However, the plants from both treatments were still considered to be 'alive' after eight weeks of shelf life testing.

10 Conclusions

10.1 Temperature Integration

Energy

Temperature integration gave savings of 12% (16 kWh/m²) when applied to a crop of Poinsettia grown in East Yorkshire. This compared well with other projects where temperature integration was applied to a range of crops on commercial nurseries including pot Chrysanthemum, Begonia and Tomatoes.

There is no doubt that temperature integration can save energy on a commercial nursery.

Crop quality & disease

In 2003 there was some difference in crop quality assessments ranging from no difference to the temperature integration treatment being slightly worse. In 2004 both crops were grown using temperature integration.

All three crops grown using temperature integration exceeded customer specification for both quality at marketing and shelf life.

10.2 Humidity measurement

Additional sensors 3

Electronic RH

- Good agreement with traditional wet & dry bulb system.
- Of the two used, one failed completely after eight months and was replaced under warranty. The second continued to show good agreement with the wet & dry bulb sensor without any maintenance after 16 months of use.

Electronic humidity sensors continue to develop and improve; those used in this project are now obsolete. Electronic sensors are relatively expensive and failure normally means complete replacement of the sensor. Assuming that their reliability has improved they offer a maintenance free (do not underestimate this benefit) option to wet & dry sensors. Where the location of measuring boxes is such that maintenance is difficult, for example over the middle of wide benches, they should be seriously considered. Their cost will be recouped through energy savings and improved climate control which in turn will produce a better quality crop.

Simple temperature Probes within canopy

These provide information on the temperatures experienced by the body of the plant.

Comparing the temperature within the canopy to the dew point temperature of the air above it gives a much more accurate assessment of the risk of a condensation event. This method offers a simple and cost effective first step towards improved plant climate control.

Infra-red camera

Great care needs to be taken in their positioning, particularly with incomplete crop canopies. Otherwise, the measured temperature will be a mixture of plant, pot and floor temperature. The ability to measure the true temperature at the surface of the crop canopy will show when radiant cooling is high, potentially causing a delay to market. Responding to this through adjustments to greenhouse temperature will help to give more reliable scheduling.

The cost of infra-red cameras and the information they provide is such that they should only be considered by growers who have a good understanding of climate control and a control system that can easily present the information to them for analysis.

Calculated 'measurements' (Software-sensors)

The calculated *Plant* humidity compares reasonably well with the true measurement during the immediate post sunrise warm up period. This is when the risk of condensation is greatest. Growers with this facility should consider its use especially when drop is used as rapid temperature rises usually follow. However, as with many of these conclusions a good knowledge of greenhouse climate control is needed first.

Canopy measuring box

A standard measuring box can be converted to extract air from within the crop canopy to give a closer representation of the conditions experienced by the crop. However, care needs to be taken in the design of the manifold to ensure that air supply to the measuring box is not restricted and artificial air movement is minimised. Practical limitations also need to be borne in mind, for example the system used in this project would be difficult to use in conjunction with moveable benches. Where mixed cropping occurs the variation in canopy humidity between crops in the same airspace may be too much to give adequate control for all crops.

All of these new measurement systems should not simply be 'turned on' and used to control temperature and humidity to the same levels as previously used. They should be compared to the *Normal* measurements over a period of time to learn the levels that are produced under current growing regimes.

10.3 Humidity control – 2004

Controlling humidity according to the RH measured within the crop canopy gave a significant reduction in the level of latent botrytis in a Poinsettia crop compared to control according to the above canopy measurement.

This gave a reduction in latent botrytis levels at marketing, 37% compared to 53%.

Although this gave a reduction in botrytis on fallen leaves during the early stages of shelf life testing it made no difference in the longer term. Work using latent disease levels as a quality / shelf life indicator is still in its infancy. This project has demonstrated one method by which it can be reduced if it is proven to benefit other crops.

Appendix 1 – Botrytis assessment

Effect of temperature integration undertaken with humidity sensors in and above the crop canopy on grey mould (*Botrytis cinerea*) in Poinsettia – 2004

Objective

To determine if the placement of temperature and humidity sensors affects the occurrence of latent and visible botrytis in Poinsettia, cv. Sonora Red, grown using temperature integration.

Methods

Crop production

Lower green leaves were collected from plants in week 36 (one week after plants were placed in the house) and week 47 (just before plant dispatch). Plants were grown from cuttings from Florema received in week 29, and were all from the same delivery batch (10512/29/H). One leaf was collected from 10 plants chosen at random in 12 bays (120 leaves in total). The bays were central in the house (9-14, 69-74) and the same bays were used on the two adjacent greenhouse blocks, A and B. Block A was the TI_{normal} treatment, block B was the TI_{canopy} treatment. Plants were grown in 13 cm pots on mypex matting over soil with drip irrigation into each pot. The crop was picked over in week 37, soon after potting, to remove dead and scorched leaves. A Fillex drench to the compost was applied for control of *Pythium* after potting.

Assessment of latent botrytis

The sampled leaves were divided into four replicate batches of 30. A 2 cm leaf disc was cut from each leaf, treated with paraquat to kill plant tissue and halt any active host resistance mechanisms, and incubated in a damp chamber. The incidence of discs developing botrytis was determined by microscope examination after 14 days. Results were examined by a two-sample t-test.

Assessment of visible botrytis

One hundred and twenty plants were examined for visible botrytis in week 48. Ten plants were selected at random from each of 12 bays (9-14 and 69-74). Botrytis was assessed using the following scale:

- 0 – Nil
- 1 – Sporulating botrytis on fallen leaves
- 2 – Sporulating botrytis on 1 attached leaf
- 3 – Sporulating botrytis on >1 attached leaf
- 4 – Stem rot (unmarketable)
- 5 – Plant collapse/dead (unmarketable)

Plants in categories 1-3 were marketable after picking over.

Shelf-life tests

Twenty plants from each block were cleaned-up, sleeved, boxed and transported in a temperature controlled van set at 15°C and ambient RH to a store at Warwick HRI Kirton, set at 15°C, and then into a shelf-life room. Occurrence of leaf and bract fall, sporulating botrytis and bract spotting were recorded weekly for three weeks, using the following indices:

Leaf and bract fall

0- nil

1 –1 to 3 leaves fallen

2- most leaves fallen from lower third of plant height

3 - most leaves fallen from lower half of plant height

4 - most leaves fallen from lower two thirds of plant height

5 - plant almost bare of leaves and bracts

Bract spotting (top 2 whorls)

0- nil

1 - up to 1% surface area affected (slight)

2 – from 1 to 10% surface area affected (moderate)

3 - more than 10% surface area affected (severe)

Plant botrytis score

0 – nil

1- spring botrytis on detached leaves

2 - spring botrytis on 1 or more attached dead leaves

3 - spring botrytis on 1 or more attached green leaves

4 - spring botrytis on 1 branch

5 - spring botrytis on 2 or more branches

Results

Latent botrytis

A low level of latent botrytis (5% of lower leaves affected) was detected on plants in both blocks at the start of the experiment (week 36), with no difference between the two blocks. Eleven weeks later, the incidence had increased to 52.5% in block A and 36.7% in block B (Table 1). This difference was statistically significant at $P=0.001$. No sporulating botrytis or lesions were visible on leaves at this time.

Visible botrytis

No visible botrytis was observed in week 36, one week after plants were placed in the house. One wilting plant with severe *Pythium* root rot was found in block B bay 70. The roots of other plants appeared white and healthy. There were occasional dead leaves on the pot surface, but no sporulating botrytis was present.

When examined on 28 November (week 48), just prior to dispatch, sporulating botrytis was present on detached necrotic leaves on the pot surface of around 60% of plants (Table 2). There was no significant difference between the greenhouse blocks. A small number of plants (2.5% in block A, 0.8% in block B) had sporulating botrytis on one lower attached necrotic leaf. All of the plants inspected were marketable. No powdery mildew or other foliar or stem diseases was observed.

Development of botrytis in shelf-life tests

Very low levels of botrytis were visible after one week, as sporulation on necrotic fallen leaves. There was significantly less on plants from block B (monitoring within the crop) than block A (monitoring above) (Table 3). After three weeks, botrytis levels were still very low and there was no difference between treatments. No bract spotting or botrytis lesions developed on plants. Most leaves from the lower third to half of the plants had fallen after three weeks, with little difference between the treatments (Table 4).

Table 1. Occurrence of latent botrytis in Poinsettia Sonora Red grown using temperature integration with sensors in different locations.

Location of sensors (greenhouse block)	Mean % leaves with latent botrytis	
	Week 36	Week 47
Above crop (block A)	5.0 (1.7)	52.5 (1.6)
Within crop (block B)	5.0 (2.9)	36.7 (1.4)
t-value	-0.0	7.51
Significance (4 df)	1.0	<0.001

Standard errors are shown in parenthesis.

Table 2. Occurrence of visible botrytis in Poinsettia Sonora Red grown using temperature integration with sensors in different locations - 26 November 2004.

Temperature integration (greenhouse block)	Mean % plants affected by sporulating botrytis, week 48
Above crop (block A)	62.5 (6.2)
Within crop (block B)	59.2 (4.8)
t-value	0.43
Significance (20 df)	0.68

Standard errors are shown in parenthesis.

Table 3. Assessments of plants in the shelf life room – plant Botrytis score.

Temperature integration (greenhouse block)	Mean score for Botrytis presence (0-5)		
	Week 1	Week 2	Week 3
Above crop (block A)	0.90 (0.069)	0.90 (0.069)	0.95 (0.050)
Within crop (block B)	0.50 (0.11)	0.75 (0.099)	0.90 (0.069)
t-value	2.99	1.24	0.59
Significance (df)	0.0054 (31)	0.22 (33)	0.56 (34)

Standard errors are shown in parenthesis.

Table 4. Assessments of plants in the shelf life room – leaf and bract fall.

Temperature integration (greenhouse block)	Mean score for leaf and bract fall (0-5)		
	Week 1	Week 2	Week 3
Above crop (block A)	1.10 (0.10)	1.55 (0.17)	2.40 (0.13)
Within crop (block B)	1.00 (0.073)	2.10 (0.22)	3.00 (0.23)
t-value	0.81	-2.00	-2.26
Significance (df)	0.42 (34)	0.053 (35)	0.031 (30)

Standard errors are shown in parenthesis.

Conclusions and discussion

Latent botrytis was detected in, or on, lower green leaves at a low incidence (5%) from soon after plants were placed in the greenhouse blocks.

Eleven weeks later, this had increased considerably. There was a significantly greater percentage of plants with latent botrytis in the block where the humidity sensor was above the crop canopy (53%) than below the canopy (37%). This may reflect a greater frequency of long-duration high humidity periods in the former.

No sporulating botrytis or lesions were observed on green leaves during crop production. Sporulating botrytis was observed only on dead leaves, and these were usually detached and on a wet compost surface.

No bract spotting or botrytis lesions were observed on plants during three weeks in a shelf-life room.

Occurrence of latent botrytis at a high incidence on the lower leaves of plants during crop production does not necessarily indicate that a botrytis problem will develop post-dispatch. It is possible that there may be a greater risk with such plants, especially if botrytis sporulation occurs at the crop base, and spores released from them contaminate upper leaves and bracts, and these subsequently develop to infect leaves (e.g. if condensation occurs during transport of plants). However, if botrytis-contaminated leaves fall onto the compost surface and dry-up they pose little risk. If they are trapped in the plant canopy, they will pose a greater risk. Removal of necrotic leaves, as usually done prior to sleeving and dispatch, should reduce the risk of subsequent botrytis development by contact spread from infected necrotic leaves.

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