FINAL REPORT

To:
Horticultural Development Council
Bradbourne House
Stable Block
East Malling
Kent, ME19 6DZ

Maximising energy saving in the production of protected ornamentals using temperature integration: the conflict with humidity control and CO_2 enrichment.

PC 206

Dr Debbie Fuller
Warwick HRI
Wellesbourne, Warwick, CV35 9EF

July 2005

Commercial - In Confidence

Grower Summary

PC 206

MAXIMISING ENERGY SAVING IN THE PRODUCTION OF PROTECTED ORNAMENTALS USING TEMPERATURE INTEGRATION: THE CONFLICT WITH HUMIDITY CONTROL AND CO_2 ENRICHMENT.

Final report 2005

Project title:	Maximising energy saving in the production of protected ornamentals using temperature integration: the conflict with humidity control and CO_2 enrichment.
Project number:	PC 206
Project leader:	Dr Debbie Fuller
Final report:	July 2005
Key workers:	Warwick HRI: Dr Steve Adams – Developed project proposal Dr Debbie Fuller – Project leader Mr Jon Horridge – Project assistant Dr Veronica Valdes – Project assistant Miss Gemma Woodward – Project assistant FEC Services Ltd Mr Tim Pratt – Consultancy (Environment/ CO_2 availability) HRI Efford: Dr Ian Clarke – Original project proposer
Location:	Warwick HRI, Wellesbourne, Warwick, CV35 9EF
Project co-ordinators:	Mr Dave Abbott, Ex SGP Ltd. Dr Ruth Finlay, Fargro Ltd. Mr Mike Holmes, Double H (Nurseries) Ltd. Mr John Phillips, Yoder Toddington Ltd.
Start date:	1 August 2004
Completion date:	31 July 2005
Key words:	Temperature integration, Pot chrysanthemum, energy.
Signed on behalf of:	**Warwick HRI**

Signature: ……………………………………………

Name: Professor Simon Bright
Director and Head of Department

Date: ……………………………………………

CONTENTS

Page No.

1. **Grower Summary**

1.1. Headline 1

1.2. Background and expected deliverables 1

1.3. Summary of the project and main conclusions 2

1.4. Financial benefits 5

1.5. Action points for growers 6

2. **Science Section**

2.1. Introduction 7

2.2. Materials and methods 8

2.3. Results and discussion 14

    2.3.1. Environmental data 14
    2.3.2. Interim assessments 27
    2.3.3. Assessments at marketing 27
    2.3.4. Assessments in shelf life 31

2.4. Discussion 34

2.5. Conclusions 39

3. **Acknowledgements** 40

Appendix 1. Experimental plan 41

Appendix 2. Breakdown of growing medium used 43

Appendix 3. Crop diary 44

Appendix 4. Photographic comparisons of treatments at marketing stage 3 46

Appendix 5. Data collected at marketing stage 3 50

Appendix 6. Photographs illustrating pot deterioration score 3 69

GROWER SUMMARY

Headline

Good quality ornamental pot plants **can** be produced during the UK winter period under supplementary lighting using temperature integration. Whilst high RH and low CO_2 can be expected to coincide with periods when accumulated temperature credits are being used, in practise this had minimal impact on final quality of pot chrysanthemums for experiments carried out over the winter 2004/05 period.

Background and expected deliverables

Climate change levy costs in addition with the escalating price of fuel, have resulted in the urgent need to provide protected crops growers with options to save energy whilst maintaining crop quality and scheduling. Previous HDC funded projects have demonstrated how temperature integration can fulfil these requirements for different ornamental and edible crops.

In spite of these developments growers remained reluctant to fully adopt the technology. This was apparently due to fears over how higher than usual humidities resulting from the lower than usual night temperatures associated with temperature integration might impact on disease incidence and plant quality. This was coupled with concerns that where CO_2 is harvested from boiler flue gasses, reduced boiler use during the day would lead to lower levels of CO_2 availability and may therefore effect plant quality.

The expected deliverables to growers from this work were to provide answers to the following quality related issues:

- Do regular periods of higher than usual humidities (as a consequence of saving energy by relaxing humidity control) have deleterious effects on pot plant quality when disease risk is taken out of the equation?

- Does reduced CO_2 availability (as a consequence of temperature integration) have deleterious effects on perceived plant quality and longevity?

Ultimately it was hoped that this would improve knowledge and therefore confidence in fully utilising temperature integration and allow growers to fully benefit from the energy savings possible.

Summary of the project and main conclusions

Pot chrysanthemums were grown over the period week 43 to week 12 2004/05, in compartments running temperature integration (including a 26°C vent temperature). A combination of the following treatments was designed to test how humidity and CO_2 availability would impact plant quality and environmental parameters.

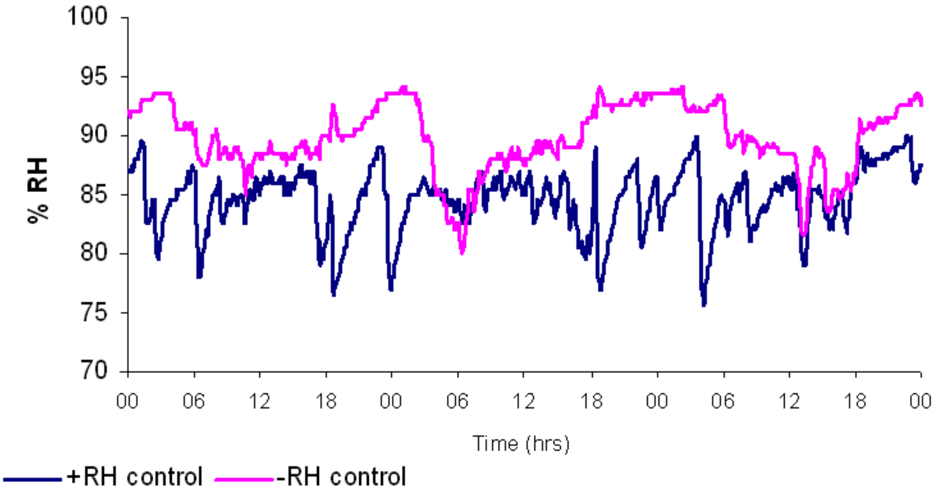
- Standard humidity control and standard CO_2 enrichment.
- No humidity control and limited CO_2 enrichment.
- Standard humidity control and limited CO_2 enrichment.
- No humidity control and standard CO_2 enrichment.

The limited CO_2 enrichment treatment was designed to restrict enrichment to periods when the compartment was being heated to represent a grower who enriches with CO_2 derived from boiler flue gases but has no heat store.

Records were kept of the aerial environment along with some localised measurements of leaf canopy conditions. Plants were assessed for quality at marketing and were also taken through a simulated transport chain, store environment and home environment to evaluate shelf life.

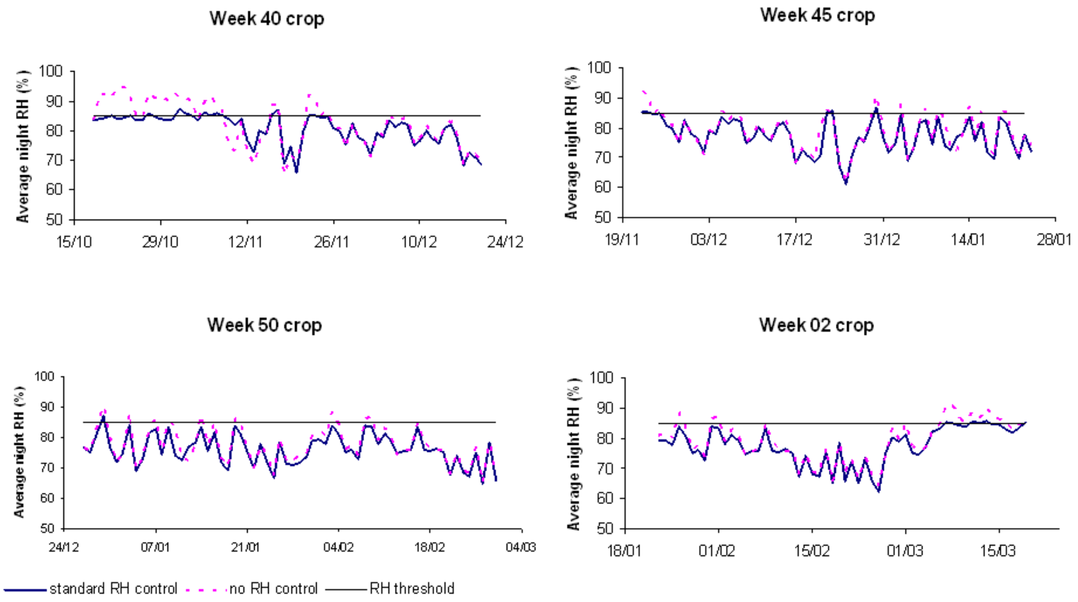
Environment

Night time RH was up to 17% higher in compartments without RH control settings compared with compartments set to use blackout gapping, venting and then pipe heat to reduce RH once the threshold level of 85% had been reached.



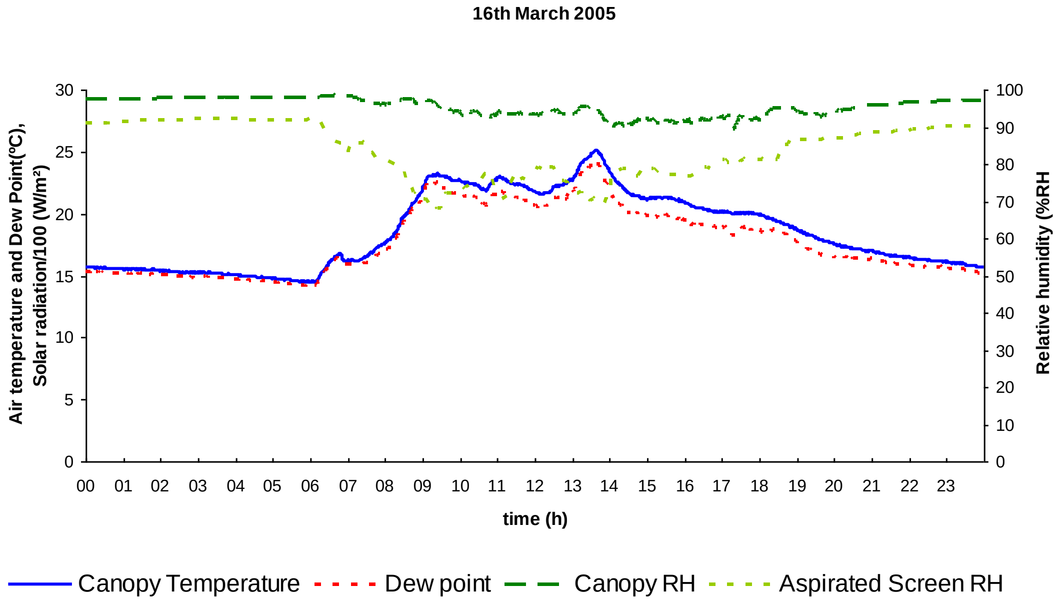
Instantaneous RH levels in standard (+RH) and no (-RH) control compartments over the period 30/10/04 to 01/11/04.

The biggest differences between the standard and no humidity control coincided with the first three weeks of short days for the week 40 crop and for the last four weeks of short days for the week 02 crop (as illustrated by the graphs of average night time RH below). Hence high humidity levels are more of a problem during the autumn/spring periods than the depths of winter due to the difference in the amount of heating required from the boiler. Furthermore the two treatments clearly demonstrated that while high RH levels can build up in association with the use of temperature credits when running temperature integration, it is entirely feasible to reduce these levels through a combination of blackout/screen gapping, venting and pipe heat.



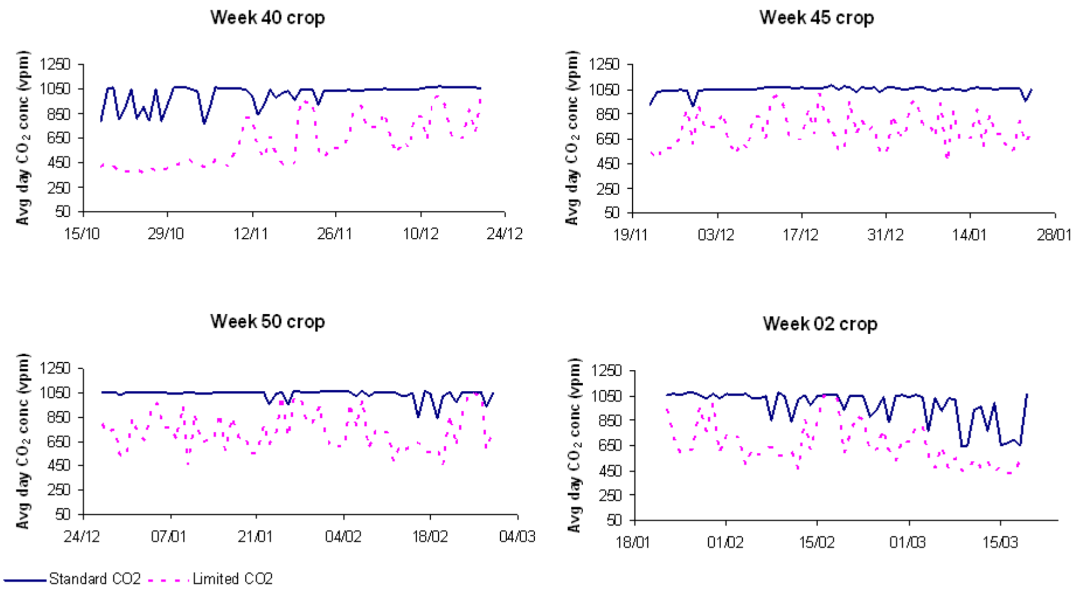
Average day time RH concentration in relation to humidity control treatments.

RH within the plant canopy was higher than that measured at the aspirated screen. For conditions that might be expected when temperature credits are being used (i.e. when air temperature was allowed to fall below the conventional set point temperature), humidity within the canopy was 97% or higher for most of the night whilst measurements at the aspirated screen were 91-92%. Although the humidity measurement for the canopy was very high, the canopy dew point temperature remained just below the leaf temperature during this period (by around 0.2 to 0.3°C). On this particular occasion therefore one would not expect to have found condensation on the leaves although clearly the leaf temperature and canopy dew point temperature were very close.



Leaf temperature, dew point and leaf and air humidity on a 'cool' day (i.e. where temperature credits were being used).

Average measured CO_2 concentration remained close to set point (1000vpm) for the standard enrichment treatment. In the limited treatment average day time CO_2 concentrations over the total short day period ranged from 605 to 733 vpm across the four crops tested. During the autumn/spring period the boiler was used less for heating than in the depths of winter and hence enrichment with CO_2 from boiler flue gases was also more limited. For the week 40 crop for example the lowest day time CO_2 concentration recorded was 370 vpm (i.e. equivalent to ambient levels). Hence the periods of highest expected light receipt coincide with the periods of lowest anticipated availability of CO_2.



Average day time CO_2 concentration in relation to humidity control treatments.

Desk based examination of the environmental data demonstrated that boiler flue gases in conjunction with a heat store of around 32.4m^3/Ha capacity would provide adequate CO$_2$ for majority of the winter period. By week 11 to 12 however improvements in the weather resulted in greater day time venting and hence an increase in the volume of CO$_2$ gas required to maintain the 1000vpm set point. At this point even the CHP scenario did not produce sufficient CO$_2$ gas.

Plant quality

Despite the differences found between environmental variables for the treatments applied, no commercially relevant differences were noted for plants grown within these treatments as demonstrated below for one of the eight varieties tested.

Dark Grace Time

Hence whilst temperature integration will encourage high RH at times and may limit the amount of CO$_2$ available at times during the day, it is unlikely that this will have a significant impact on pot chrysanthemum quality. Growers of cut flowers however should be aware of the dry weight reduction that may result from limitation in CO$_2$ availability in the absence of a heat store at the start and end of the growing period investigated here.

Financial benefits

Plant quality was not compromised by the high RH levels achieved in treatments that had no settings designed to reduce RH. Removing RH control would have a financial benefit which was quantified through energy monitoring. In the experimental compartments used (95m^2), 7 to 10% more energy was consumed to control humidity for crops stuck in weeks 40, 50 and 02 crops. This is equivalent to an increase of 2-3 kWhr/m^2 for the total period of short days for each crop. (There was little difference in energy consumption between the + and - RH control treatments for the week 45 crop due to the higher heat demand). Assuming a gas price of 2p/kWhr and high boiler efficiency (85%), this would amount to 7p per m^2 per crop which seems a small figure. However since humidity control is used year round this can be converted to an annual figure of £4,550 per hectare. Although no disease problems were experienced for majority of this experiment, an outbreak of *Puccinia horiana* (chrysanthemum white rust) did occur at the end of production of the week 02 crop. Hence growers will need further guidance on how to relax humidity control in order to save energy whilst minimising disease risk. Work in the Defra project HH3611SPC aims to address this issue further.

A decrease in plant dry weight resulted from the restriction on available CO_2 resulting from the limited CO_2 enrichment treatment. However, overall the quality of plants from all treatments was judged to be acceptable for commercial purposes. These results do not suggest that CO_2 set points should be lowered since the limited CO_2 enrichment treatment in these studies did achieve the 1000 vpm set point when heating was also in use. Furthermore, external temperatures towards the end of these studies (late February and March 2005) were atypically low. In a more ‘normal’ year therefore more use of integration may be possible in early spring and hence lower achieved CO_2 concentrations would be expected. These results should however enable growers to now use temperature integration with greater confidence and fully realise the predicted 10-15% energy savings calculated in previous HDC funded projects.

Action points for growers

- Growers who are using supplementary lighting should implement temperature integration for winter ornamental pot plant production to ensure they meet the energy efficiency targets required for the climate change levy rebate system and to save energy without fears over compromising quality. Integration using a high vent set point (26°C) and minimum temperature of 15°C from 09:00-06:00 and of 13°C from 06:00-09:00 produced good quality plants in this experiment when supplementary lighting was used throughout short days.

- Late autumn and early spring are the main periods when growers might expect to see the highest RH levels and lowest CO_2 levels due to the reduction in boiler use through the accumulation of temperature credits. Growers should be particularly vigilant for disease problems at these times.

- Temperature integration can be combined with settings to control RH through blackout/screen gapping, venting and pipe heat. Hence concerns over high RH should not put growers off using Ti to save energy. Since RH control settings do themselves increase energy use growers should aim to target RH control towards periods of greatest need. Information to support such decisions should be available from associated Defra funded work in the near future.

SCIENCE SECTION

2.1. Introduction

Trials with pot chrysanthemums and poinsettias at Efford (HDC project PC 190), commercial trials with pot chrysanthemums at Double H Nurseries (PC 197), and Defra-funded research at Wellesbourne and Silsoe, have combined to show that temperature integration (using higher than normal vent temperatures) has the potential to save around 15% energy per annum in the commercial growing of pot plants. In spite of this, however, there is nervousness on the part of growers to fully adopt the technology. This appears not to be related to the availability of suitable environmental computers able to run temperature integration programs, but rather to fears over the effects of higher than usual humidities on disease incidence and quality, and on the effects of reduced CO_2 levels on quality when CO_2 is taken from boiler flue gases.

Temperature integration results in higher than usual day temperatures, and lower than usual night temperatures, and this combination determines that night-time humidity levels in particular are frequently very high. High humidities increase disease risk and, possibly, reduce quality, so humidity control strategies are routinely brought into play (gapping screens, venting and re-heating) at levels lower than those judged to be potentially dangerous. As a consequence, much of the potential energy saving from temperature integration is lost. It is probable that growers bring humidity control into play much earlier than is strictly necessary from the standpoint of protecting against fungal diseases such as chrysanthemum white rust. However, current practices with regard to humidity control are unlikely to change greatly until strategic research (funded by Defra) has been carried out to relate humidity levels and durations to disease risk. Such research will examine whether higher humidity levels can be tolerated than is currently the case, to enable greater energy savings to be made from temperature integration. However, such higher than usual levels of humidity will only be tolerated if growers are also convinced that quality at point of sale and during post-harvest life is not likely to be compromised as a result. Fears over pot plant quality when humidities are regularly high will be addressed in parallel with strategic studies relating to disease incidence and spread.

Temperature integration usually saves energy by utilising solar gain and reducing the frequency of boiler operation. However, for all of those growers who take CO_2 from boiler flue gases, this has the unfortunate consequence that CO_2 is not available for enrichment when daytime temperatures are high as a result of solar gain. This means that levels of net photosynthesis will be reduced to below those that would have been achieved with enrichment and this may reduce subsequent quality. Growers are concerned to quantify the potential consequences of reduced CO_2 on pot plant quality.

Objectives

To address the following quality-related questions that currently stand in the way of further take-up of temperature integration as an energy saving technology:

- Do regular periods of higher than usual humidities (as a consequence of saving energy by relaxing humidity control) have deleterious effects on pot plant quality when disease risk is taken out of the equation?

- Does reduced CO_2 availability (as a consequence of temperature integration) have deleterious effects on perceived plant quality and longevity?

2.2. Materials and methods

2.2.1. Treatments

Two humidity treatments and two CO_2 enrichment treatments were combined in a 2 x 2 factorial experiment in four 95 m^2 glasshouse compartments as follows:

- Standard humidity control and standard CO_2 enrichment.
- No humidity control and limited CO_2 enrichment.
- Standard humidity control and limited CO_2 enrichment.
- No humidity control and standard CO_2 enrichment.

These treatments were imposed as follows:

Standard humidity control:-

venting, heating and blackout gapping were introduced when relative humidity rose above 85%. Settings varied depending on the blackout position. <u>During the day</u>, vents opened 1% at an RH of 85% and increased by 2% for every further 1% increase in RH. Above 88% RH, pipe heat at 35°C was introduced which increased by 2°C for every further 2% increase in RH. <u>At night</u>, the blackout was gapped by 1% at 85% RH. The gap was increased by 1% for every further 2% rise in RH to a maximum blackout gap of 4%. At 88% RH, 1% vent was introduced and this increased 1% for every further 2% increase in RH. At 90% RH, pipe heat of 35°C was introduced, increasing by 2°C for every further 2% increase in RH.

No humidity control:-

none of the influences available in the climate control computer were used to regulate humidity.

All compartments were equipped with under bench capillary matting which was automatically irrigated hourly during the day and every two hours at night to achieve suitably high background RH levels.

Standard CO_2 enrichment:-

pure CO_2 was piped into the compartment to achieve a concentration of 1000 vpm when the vents were less than 5% open, with the target concentration ramping down to 350 vpm when vents were more than 10% open.

‘Limited’ enrichment:-

settings for enrichment were as for the standard treatment, but enrichment could only take place when the boiler was operating to represent a nursery using CO_2 derived from flue gases for enrichment but with no dump tank. This was achieved using a uniswitch to limit enrichment to periods when the pipe temperature was 3°C higher than air temperature.

Temperature integration and supplementary lighting to a target level of 13.9 W/m^2 PAR were used as standard in all compartments throughout short days.

Plants stuck in weeks 40, 45, 50 and 02 were grown in the treatments described above.

Eight varieties were used for each stick week. These were: Chesapeake, Covington, Dark Grace Time, Dark Swing Time , Energy Time, Irvine, Sockeye Time, Surf. Appendix 1 provides details of plot and compartment layout.

2.2.2. Cultural details

Plant material

Unrooted cuttings of each variety were purchased from commercial propagators as detailed in table 1.

Table 1: Cultivars used

Cultivar	Supplier	Flower Colour	Height class	Response (days)
Chesapeake	Yoder Toddington Ltd	Yellow	M	52
Covington	Yoder Toddington Ltd	Yellow	S	49
Dark Grace Time	Cleangro Ltd	Purple	M	52
Dark Swing Time	Cleangro Ltd	Bronze	MT	54
Energy Time	Cleangro Ltd	Red	MT	52
Irvine	Yoder Toddington Ltd	Deep Pink	M	54
Sockeye Time	Cleangro Ltd	Pink	M	52
Surf	Yoder Toddington Ltd	White	M	49

Propagation and long days

14D pots were filled with Scotts Longfield Mix compost (see Appendix 2 for details), lightly watered and sheeted over on heated benches (set to achieve a minimum of 21°C within the compost) 24 hours prior to sticking. Five cuttings were stuck in a pot.

After sticking, cuttings were watered in with a Nemasys drench and treated with *Hypoaspsis miles* (at 150 mites/m²) before sheeting over with clear polythene.

The propagation compartment was set to heat at 18°C and vent at 24°C. Overhead shade screens were set to close at 350 W/m² during the day and were closed for energy saving at night.

Cyclic lighting via tungsten bulbs set to a minimum of 0.5 W/m² (total) was used on a 15 minutes cycle between 23:00 and 04:00 (ending with lights on), to give long days whilst the cuttings were sheeted and for the first night that sheets were removed.

Sheets were removed late afternoon 10 days from sticking and cuttings weaned by misting.

Assimilation lighting was then used at 13.9 W/m² (PAR) for 24 hours a day to maintain long days. At this point, enrichment with CO_2 was introduced, set to 1000vpm when vents were less than 5% open, ramping down to 350vpm once vents were more than 10% open.

Daminozide was applied as Dazide, at 1.0 to 1.5 g/l to all cuttings after sheets were removed.

Pots were irrigated with dilute feed as required (see nutrition).

Pots received 18 long days before being moved in to short day compartments for treatments.

Short day environment

All compartments were given temperature integration via a Priva Integro 720 climate control computer as follows:

- Average air temperature 18.5°C.
- Ventilation temperature 26°C.
- Maximum negative compensation 3.5°C, rising to 5.5°C from 06:00 to 09:00 (i.e. a minimum temperature of 15°C, dropping to 13°C for the first three hours of the day).
- Averaging set over 3 days.

Compartments were also lit with assimilation lighting from 06:00 to 18:00 daily with lights set to give a target irradiance of 13.9 W/m² (PAR).

Blackouts were set to open at 06:00 hrs and close at 18:00 hrs daily (GMT) to give short days. Energy saving settings were also used which linked blackout position to a light intensity of 3 W/m² total solar radiation when days were naturally short.

Growth regulation

Pots were pinched when plants were approximately 8-9cm tall to leave a plant of around 7 cm in height with 7 to 9 leaves. The youngest leaf left on the leg was at least ¾ expanded with the pinch removing around 1.0 to 1.5 cm of growth. Pinching was also timed to cover all varieties at the same time or as close to this as possible to ensure the post pinching daminozide could be applied to all plots at the same time.

Daminozide as Dazide was applied at 1.5 g/l approximately 10 days after pinching when the first leaves on the new breaks were expanding and starting to flatten out with around 2cm of new shoot growth. Plant height was then monitored weekly against data collated by Double H nursery in previous years for tracking growth and taking decisions about follow up applications of Dazide. The maximum number of Dazide applications for any one variety was set to 3.

Actual timings of pinching and Dazide applications are recorded in the crop diary in Appendix 3.

Pot spacing

Pots were kept at pot thick throughout propagation and long days. They were moved to intermediate spacing (25 pots/m^2) when put into short days, and to final spacing (14.5 pots/m^2) two weeks after the start of short days.

Nutrition

Base fertilisers in the compost supplied 180 mg/l N, 150 mg/l P and 299 mg/l K. Capillary matting on all benches was irrigated manually through seep hose according to plant needs. Liquid feeding was applied at each irrigation to provide 300 mg/l N, 26 mg/l P and 207 mg/l K.

Pest and disease control

Cuttings were treated with propiconazole as Bumper (0.4 mls/l) at sticking to prevent Chrysanthemum white rust. No further fungicide treatments were necessary.

Intercept 5GR was incorporated into the compost at 280 g/m^3 for prevention against sucking pests.

Predators were routinely introduced to each crop according to the following schedule:

- *Hypoaspis miles* (at 150 mites/m^2) before sheeting over newly stuck cuttings against *sciarids.*

- *Steinernema feltiae* as Nemasys, at 0.5 million/m^2 against *sciarids* and *thrips*, applied when watering cuttings in after sticking.

- *Phytoseiulus* for Red Spider Mite at 10 mites/m², after 3 weeks of short days.

- *Amblyseius cucumeris* at 200 mites/m² or 1 sachet/m² as each batch of pots began to develop buds.

Weeds around the edges of compartments were sprayed with Talstar at 6 week intervals to prevent Red Spider Mite. The matting underneath benches was sprayed monthly with Panacide-M at 1l/20l to prevent algae growth and hence establishment of *Scatella* flies or *sciarid*s.

Home life environment

Environments comprised of transport, store and home phases.

Transport phase:-

sleeved, boxed plants were held at 15°C for 16 hours, 12°C for 8 hours and 18°C for 16 hours, RH at 65% throughout.

Store phase:-

sleeved plants were removed from boxes and stood on benches covered with capillary matting for 10 days. Air temperature was set to 18°C day and night, RH at 65% in the air and fluorescent strip lighting was given for 12 hours a day at 600 lux. Plants were watered with tap water via the capillary matting as required.

Home phase:-

sleeves were removed from the plants and they were stood out on saucers. Air temperature was set to 18°C day and night, RH at 65% and lighting with fluorescent strip lighting for 12 hours a day set to 600 lux. Plants were watered with tap water via the saucers as required.

Figure 1 – Illustration of the room used for testing store and home life phases:

Assessments

Environmental records

Total and PAR radiation (external and internal)
Compartment air temperature
CO_2 levels achieved and logged inputs as CO_2 obtained from gas
Relative humidity (RH)
Logged heat and electricity use
Leaf and canopy measurements of temperature and RH with calculation of dew point (i.e. the air temperature at which water vapour in the air will form condensation).

Production records

Time to harvest (HDC stage 3).
Number of flowers at stage 5 (Cockshull & Hughes, 1972) and above
Flower colour score
Plant height from pot rim to base of tallest flower per plant
Plant diameter
Destructive sub-sample of 5 pots per plot to give shoot fresh and dry weights
Compost and leaf nutrient analyses at harvest
Interim and final harvest assessments of leaf colour and lower-leaf quality.
Observations of disease incidence at regular intervals during production period.
Photographic records of each treatment at marketing

Shelf life records

Number of buds per pot at stage 5+
Number of distorted buds per pot
Qualitative assessment of foliage appearance, scored as follows:

1 = All green
2 = Green with a tinge of yellow
3 = Half green, half yellow
4 = Mostly yellow / brown
5 = Brown or leaves dropped

Qualitative assessment of flower appearance scored as:

1 = No deterioration
2 = Degeneration visible in flower centre
3 = Flower wilting / necrosis

Measurements of water loss (leaf transpiration and stomatal conductance)

2.3. Results and discussion

2.3.1. Environmental data

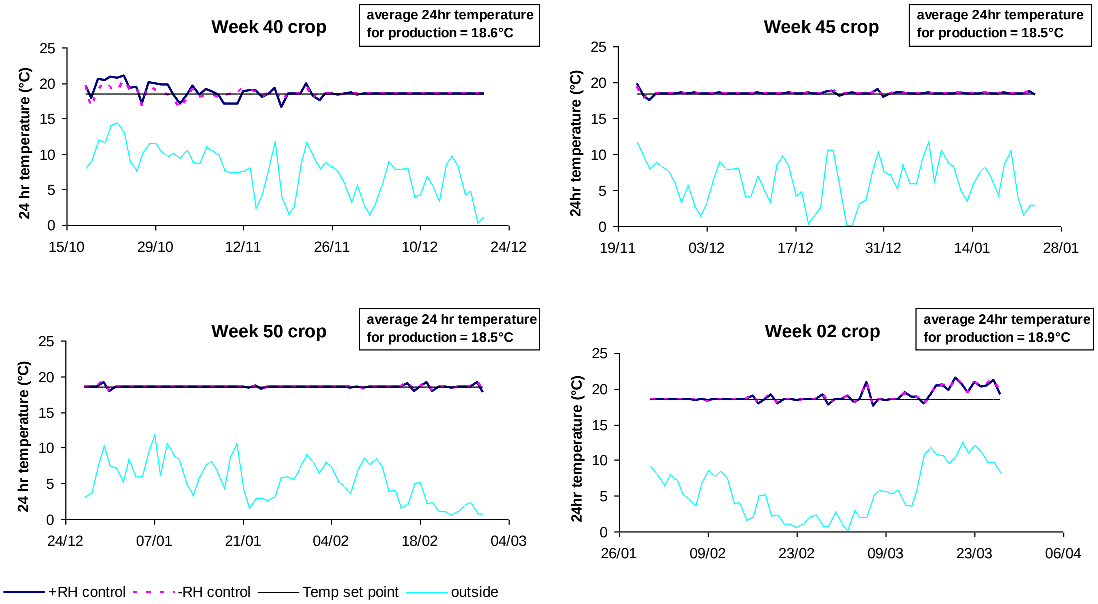
Temperature

Achieved 24 hour temperature for crops from all stick weeks was very close to the 18.5°C set point (figure 2). These data also illustrate the extent of temperature integration achieved for each crop. For example, the crop stuck in week 40 and moving into short days on 18th October, built up sufficient temperature credits via solar gain to allow the temperature to fall below the 18.5°C average for significant periods until the end of November. Average 24 hour temperature therefore fluctuates around the set point temperature as solar gain is accumulated and then used as credits (i.e. when achieved temperature was allowed to fall below set point). In fact in these early weeks more temperature credits were accumulated than it was possible to use.

From December onwards, however, average 24 hour temperature remains close to the 18.5°C set point. This coincides with less solar gain and more use of the heating system. The week 02 crop also began to benefit from an increase in temperature credits over the last 3 weeks of short days with greater fluctuation of achieved temperature around set point temperature for this latter part of production. This period might have been expected to span a greater proportion of the total production time of the week 02 crop, but a cold snap occurred during February requiring more glasshouse heating than might normally be expected for this time of year. External temperatures demonstrate how this cold snap related to stage of production of the week 02 crop.

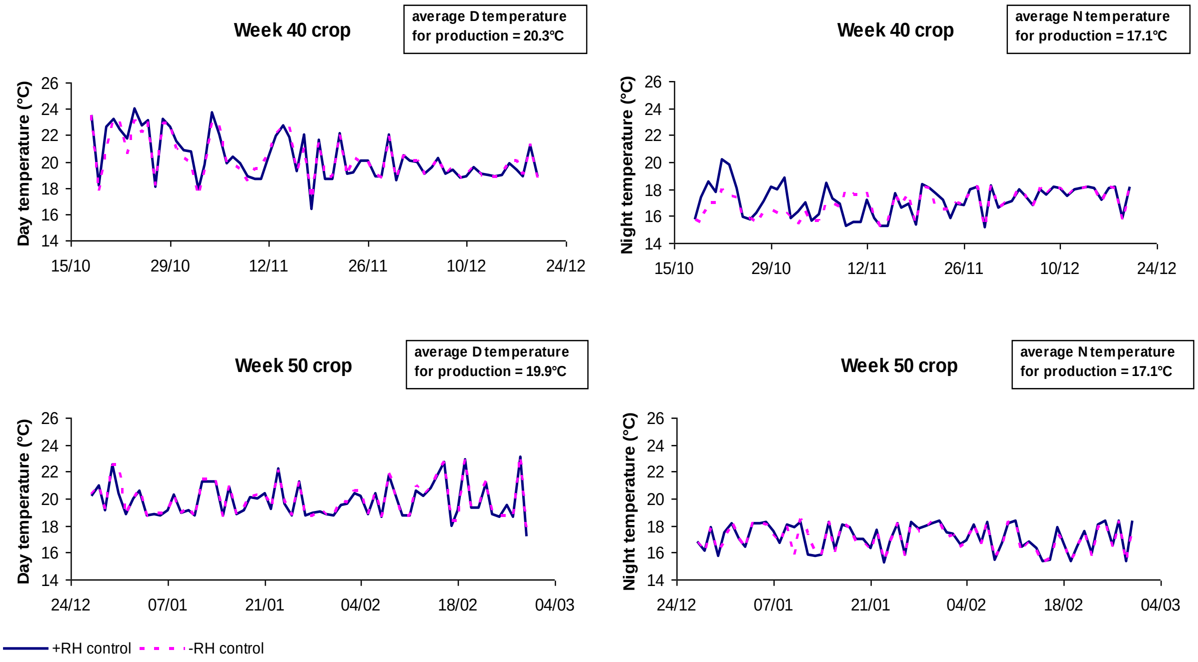
These data also demonstrate the impact of humidity control on achieved temperature. For the first three weeks of the week 40 crop for example, average 24 hour temperature for the compartments with settings to regulate humidity was up to 1.5°C higher than the compartments without humidity control settings.

Figure 2. Average achieved 24 hour temperature compared with set point.



Differences between achieved day and night temperatures were also noted. Day temperature was overall higher than night temperature regardless of the amount of solar gain and thus temperature credits were available on most days (figure 3). Hence for both the week 40 and week 50 crops, average achieved day temperature (20.3°C and 19.9°C respectively) was higher than average achieved night temperature (17.1°C for both crops). There is also greater fluctuation in both day and night temperature from day to day compared with 24 hour average temperature discussed above which demonstrates the success of the integration programme in maintaining desired average temperature. This is particularly beneficial to chrysanthemum which flowers most rapidly at set point temperatures conventionally used commercially and hence is delayed by temperatures which are either above or below set point.

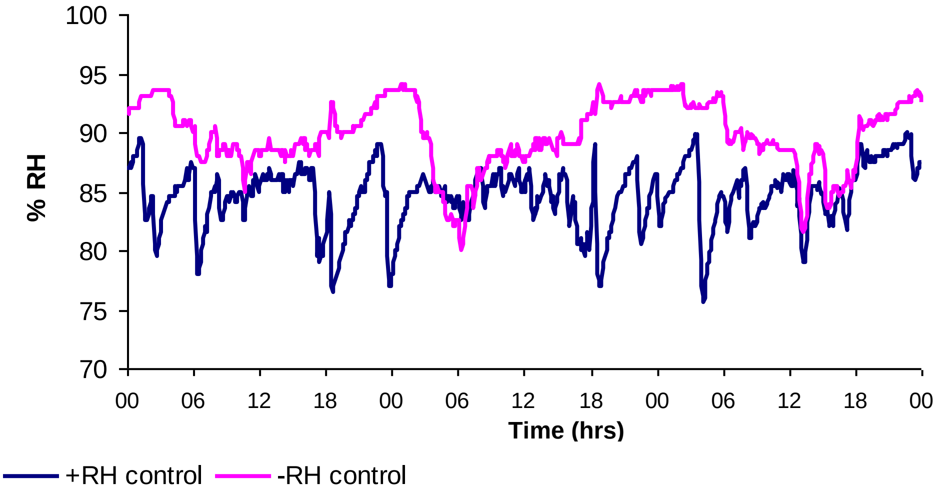
Figure 3. Average achieved day and night temperatures compared with set point for week 40 and 50 crops.



Humidity

RH within the experimental compartments were found to be at suitably high levels to be representative of commercial nurseries as demonstrated in figure 4 of levels collected over 3 days from 30/10/04.

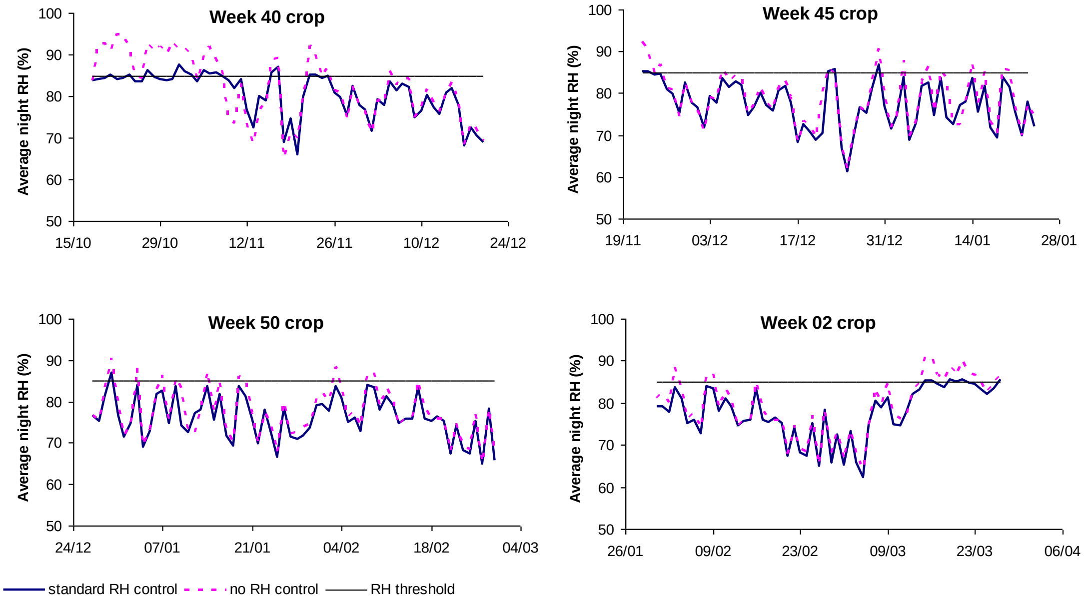
Figure 4. Instantaneous relative humidity levels in standard and no humidity control compartments on 30/10/.04 to 1/11/04.



Average RH was compared separately for each 12 hour day and 12 hour night period. Figure 5 illustrates these data for each of the crops grown. Whilst background RH levels were found to be realistic, problems associated with high RH were restricted to specific periods of production only. For the crop stuck in week 40, background night time RH was high for the first three weeks of short days with average night time RH up to 10% higher in the unregulated treatment compared with the standard treatment. After this, treatments generally had similar average night time RH for the remainder of production. Night time RH was similar in both treatments for crops stuck in week 45 and week 50. Differences in average night time RH became apparent again for the crop stuck in week 02 particularly over the last 4 weeks of production. Overall differences in achieved humidity between treatments were greatest for the week 40 crop. In other years, differences of a similar scale to those noted for the week 40 crop might also be expected for crops grown in Spring. In 2005 there was an unusually cold period in mid-late February and hence greater use of the heating system than might otherwise be expected for temperature integration at this time of year.

These differences coincide with the use of temperature credits under temperature integration. Hence where credits had been accumulated and were being used, air temperature was allowed to fall below conventional set point temperature and RH increased. Despite this increase in the unregulated RH treatment, the standard RH control treatment was maintained close to the 85% threshold level set. In summary, when using temperature credits an increase in RH does occur but it is clearly possible to use influences within the environmental control computer to regulate RH when temperature integration is in use. The energy use implications of this approach are discussed below.

Figure 5. Average RH in standard RH control and no RH control treatments.

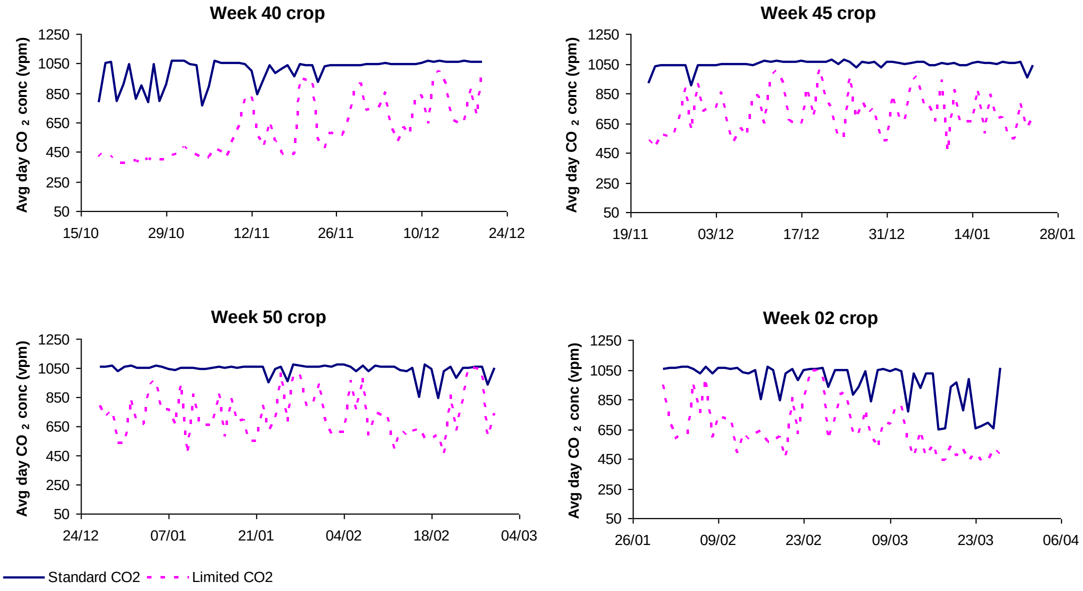


CO_2 concentration

Achieved instantaneous CO_2 concentration quickly reached the 1000vpm set point when enrichment was required and when other conditions were not restricting supply (i.e. vent position and in the case of the limited treatments, heat demand). Hence, average achieved CO_2 concentration remained close to set point (1000vpm) for the overall production period of each crop receiving the standard enrichment treatment (figure 6). Limiting CO_2 enrichment to periods of active heating only, reduced average daily achieved CO_2 concentration to between 605 and 733 vpm across the four crops tested. The degree of separation for achieved CO_2 concentration between standard and limited CO_2 enrichment treatments varied with timing. For the week 40 crop for example, achieved CO_2 concentration was 346 to 663 vpm lower than in the standard CO_2 enrichment treatment over the first three weeks of short days. This coincides with the period of greatest treatment separation for humidity control treatments described above and again relates to the amount of temperature credits available and hence the amount of heating applied.

Even with crops that required a greater amount of heating due to the lower accumulation of temperature credits (i.e. week 45 and week 50 crops), there was a clear separation between treatments in terms of average achieved daily CO_2 concentration. However average day time CO_2 concentrations remained above 460 vpm for both of these crops.

Figure 6. Average achieved day time CO_2 concentration in standard and limited enrichment treatments.

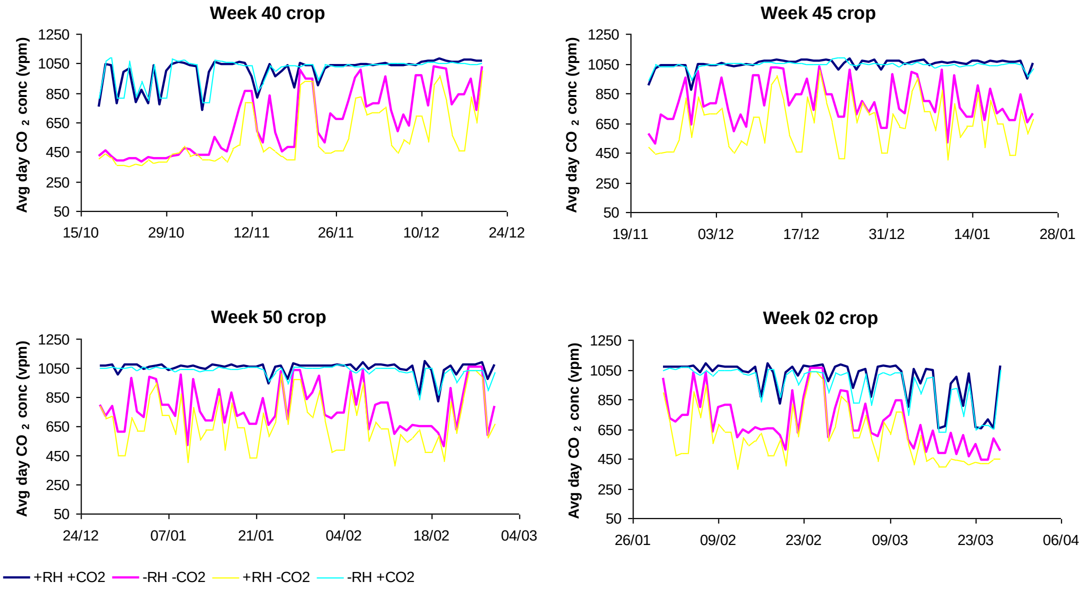


Interaction between RH control and achieved CO_2 concentration

With standard CO_2 enrichment, both the +RH control and the –RH control treatments achieved the target level of 1000vpm consistently with little difference between them. The treatment that included standard humidity control had increased venting during periods of high achieved RH but since CO_2 enrichment continued at a set point of 1000 vpm until vents were 5% open and the amount of venting required to reduce humidity was also low there was no resultant restriction on achieved average CO_2 concentration (figure 7).

With limited CO_2 enrichment, the day time heat demand for the +RH control treatment was only slightly higher than that for the –RH control treatment. This allowed more CO_2 enrichment to take place but also caused more CO_2 loss through venting (since this treatment would not be enriching in these treatments until pipe heat was also called for). The net effect was that at times, the +RH treatment achieved lower daytime CO_2 levels than the -RH treatment. Achieved CO_2 levels in the limited regime were also more variable than the treatments with standard enrichment and factors such as how accumulation of CO_2 via night time respiration (of plants and compost and soil micro flora) influenced concentration at times that dosing was possible due to the use of heating would have contributed to this variation.

Figure 7. Average day time CO_2 concentration in relation to humidity control treatments.



Energy Use

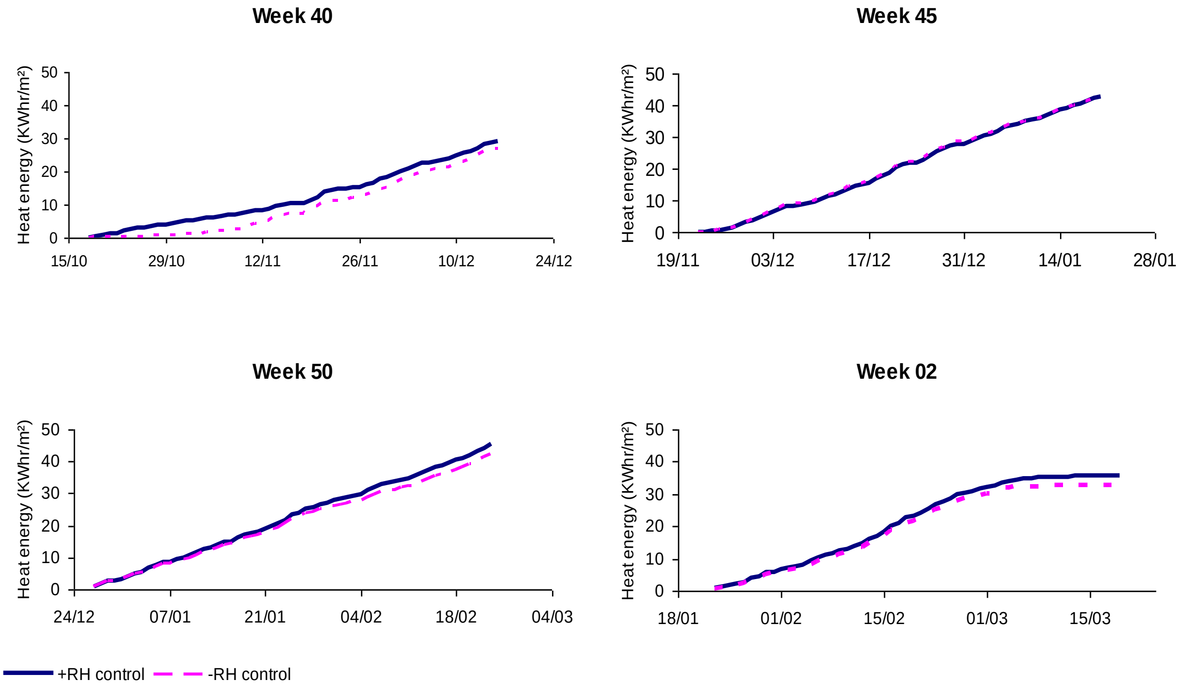
As may be predicted, the crops stuck in weeks 45 and 50 and therefore grown during the period of lowest solar gain and external temperature required the highest heat energy inputs (table 2) at 46-52 $kWhr/m^2$ for the total SD period. In contrast the week 40 and 02 crops required the lowest levels of heat energy at 33-36 $kWhr/m^2$. That is a difference of 37% between highest and lowest energy consumption per crop.

Table 2. Total energy consumption per crop.

	kWh/m^2		
Stick week	**+ RH control**	**- RH control**	**% difference**
40	34.8	32.5	7.0%
45	46.0	45.5	1.1%
50	51.5	48.2	6.8%
02	35.8	32.6	9.8%

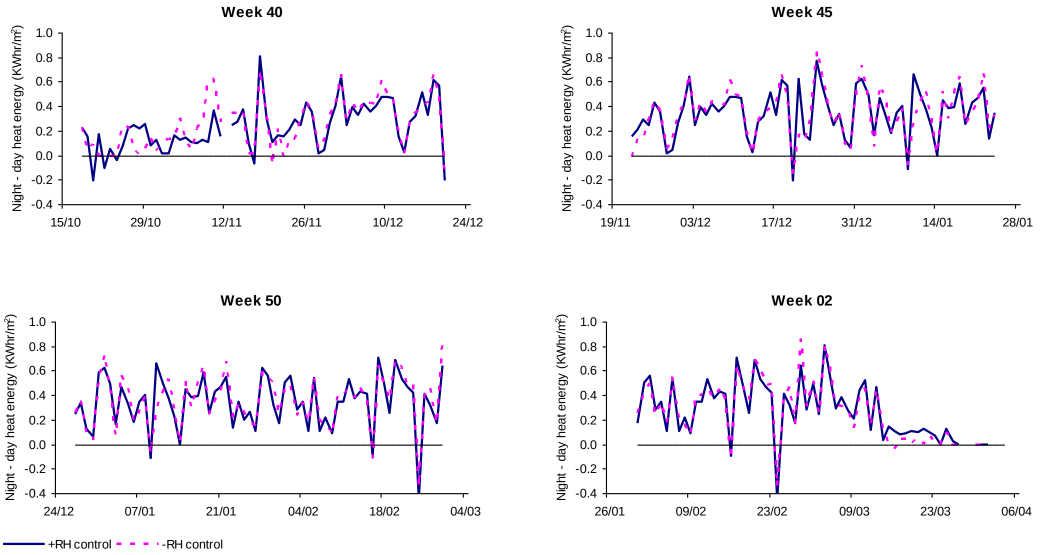
As mentioned previously, RH control influenced energy consumption (figure 8). That is, during periods of high ambient humidity and hence periods when pipe heat would be used to control humidity, heat energy consumption also increased. This is particularly apparent for the first 3 weeks of short days of the week 40 crop and over the last 3 to 4 weeks of production of the weeks 50 and 02 crops. Heat energy consumption for the week 45 stuck crop was unaffected by humidity control settings but this crop also had comparable RH levels throughout production as a result of greater use of the heating system to control temperature. The increase in energy consumption required to control humidity equates to 7%, 1%, 7% and 10% of the energy consumed by the compartments without humidity control for the week 40, 45, 50 and 02 crops respectively.

Figure 8. Cumulative heat energy consumption in relation to humidity control settings.



Heat energy consumption was greater during the night (i.e. 18:00 to 06:00 hrs) than the day (06:00 to 18:00 hrs) on all but a few days of the experiment (figure 9). Since these data illustrate the differences between the day and night, positive figures illustrate where more energy was consumed at night and negative figures illustrate where more energy was consumed during the day. Trends relating to differences in energy consumption due to RH control which have been discussed above are also apparent in these graphs demonstrating how heat demand at night relates to pipe heat for humidity control as well as a general need for heating to maintain average temperature. As an average over the experimental period (week 43 to week 12), 50% less energy was used during the day than during the night. Where there was no RH control, day energy use was 70% lower than night energy use.

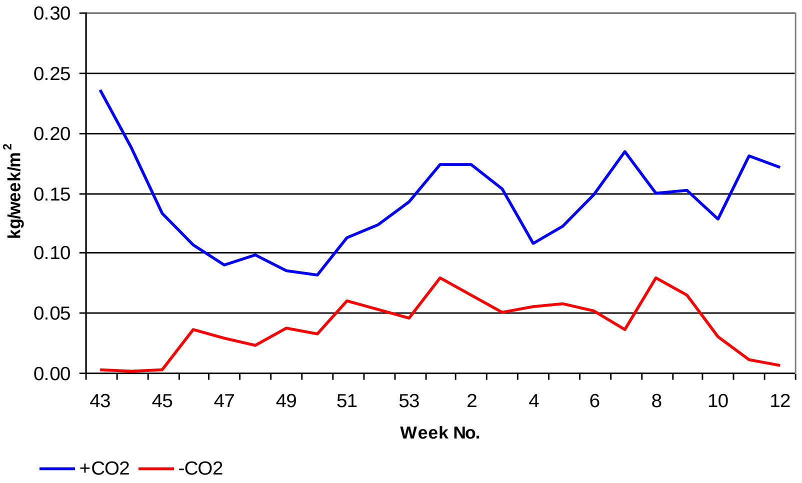
Figure 9. Differences in heat energy consumption between day and night and in relation to humidity control settings.



CO$_2$ use

As would be expected, the standard CO$_2$ enrichment treatments used significantly more kg/m^2 per week than the limited treatments (figure 10).

Figure 10. Average CO$_2$ use for standard (+CO$_2$) and limited (-CO$_2$) treatments



CO$_2$ availability

Environmental data summarised above was used to evaluate the implications of CO$_2$ availability in combination with temperature integration for difference scenarios of CO$_2$ supply. The following summarises this work.

Boiler without heat storage

In this situation CO_2 would only have been available if heat was being used at the same time that CO_2 was required. This was essentially how the limited CO_2 treatment was operated.

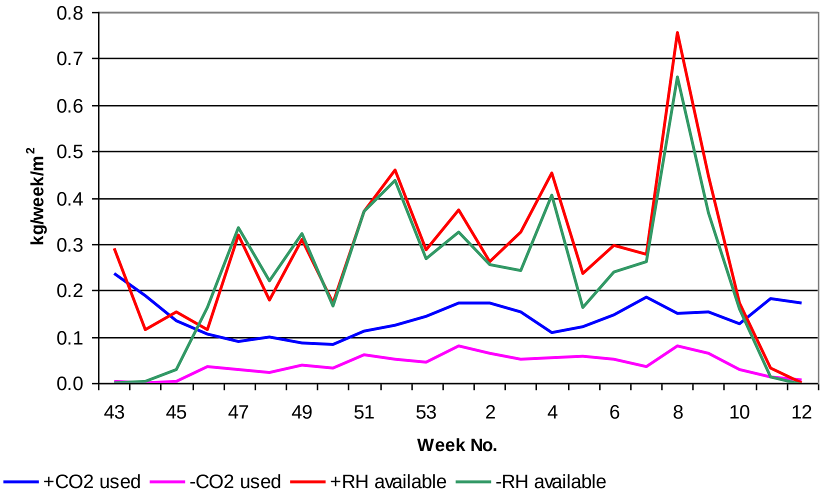
The total amount of CO_2 available during the daytime period in this scenario was calculated from the daytime energy use for each energy treatment (+RH control and -RH control treatments).

- At a heating system efficiency of 85%, 1kWh of hot water heat is produced from 1.18kWh of mains gas
- The combustion of 1kWh of mains gas produces 0.19kg of CO_2
- Therefore the consumption of 1kWh of hot water heat will produce 0.22kg of CO_2

Figure 11 shows that from week 45 to week 10, the amount of CO_2 that would have been available from the daytime heat consumption easily exceeded the amount used in all cases. Prior to week 45 the CO_2 availability from the +RH treatment closely matched that consumed in the -CO_2 treatment. Whereas the availability of CO_2 from the -RH treatment was significantly less but still sufficient to supply the amount used by the -CO_2 treatment.

From week 11 onwards CO_2 availability was only sufficient to meet the needs of the limited CO_2 treatment regardless of the RH control.

Figure 11. Comparison of CO_2 use with availability (boiler, no heat storage)

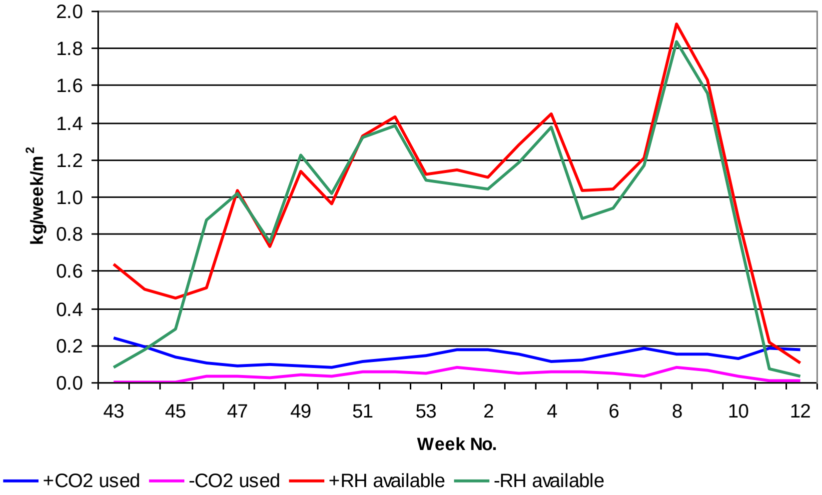


Boiler with heat storage

In this scenario CO_2 would have been available at any time as long as the heat store was not full. Figure 12 shows the amount of CO_2 that would have been available assuming that all the gas burnt to produce the heat used also produced available CO_2 i.e. the heat store was infinitely large.

A similar trend is evident to that in the no heat storage scenario. The main difference being that prior to week 45, the +RH control treatment easily had sufficient CO_2 available for even the standard CO_2 enrichment treatment.

Figure 12. Comparison of CO_2 use with availability (boiler, with heat storage)



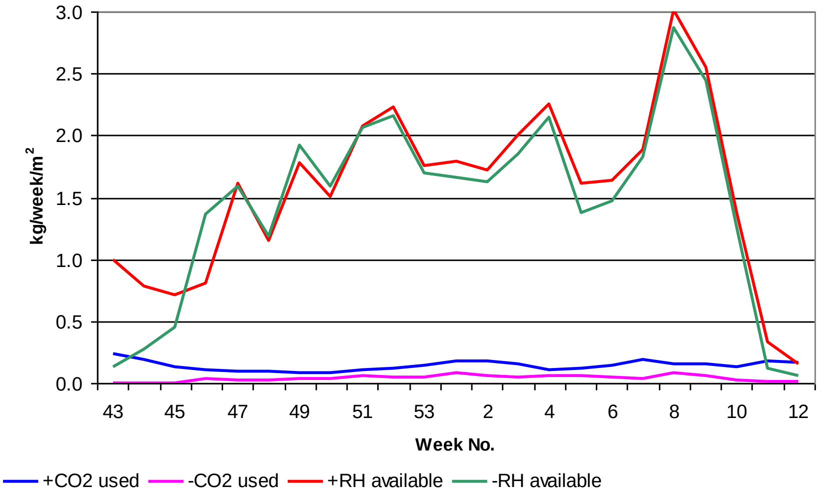
The size of the heat store cannot be completely ignored. The peak heat demand occurred in week 9 and was 8.6 kWh/m^2 for the week i.e. 1.23kWh/m^2 per day. A heat store capable of storing this much heat equates to a capacity of 210m^3/Ha. Standard recommendations suggest a heat storage system capacity of 200m^2/Ha for CO_2 enrichment purposes. Therefore the assumption that sufficient CO_2 would be available in this scenario was a reasonable one.

CHP

In this scenario all the heat demand would have been met by a CHP installation with heat storage. With any surplus electricity produced being exported to the national grid. Therefore the availability of CO_2 per kWh of heat used is much higher (0.35 kg / kWh).

The trend seen in the previous scenarios continues albeit with an even greater surplus of CO_2 (figure13).

Figure 13. CO_2 use vs. availability (CHP)



Canopy environment

Canopy RH was higher than aspirated screen RH during the day and night as shown in figures 14 and 15 for measurements taken in a compartment without humidity control. For the 24 hour period of 16th March, humidity within the canopy was 97% or higher during the period 00:00 hrs to 06:00 hrs. This compares with an aspirated screen RH measurement of 91-92%. Interestingly, although the humidity measurement for the canopy was very high, the canopy dew point temperature remained below the leaf temperature throughout this period (by around 0.2 to 0.3°C). Hence one would not expect condensation to be apparent on the leaves. It should be noted however that the canopy measurements were not aspirated and hence provide only an indication of differences which will be subject to localised changes.

The data for the 6th March can be compared with that from 16th March to give a comparison of the effects of different air temperatures (figures 16 and 17). During the early hours of 6th March, the compartment was being heated, as apparent from the cycling of aspirated screen air temperature. At this time, canopy humidity was around 90-91% whilst aspirated screen humidity was around 62-64%. This resulted in a greater separation between canopy dew point temperature and leaf temperature (0.7-1.5°C) than was measured during the same period on the 16th March. Air and leaf temperatures were also higher during the day on 6th March and again a greater separation between dew point and air/leaf temperature resulted compared with the same period on 16th March.

Figure 14. Measurements of RH, temperature and humidity at the aspirated screen on a ‘cool’ day (i.e. where temperature credits were being used).

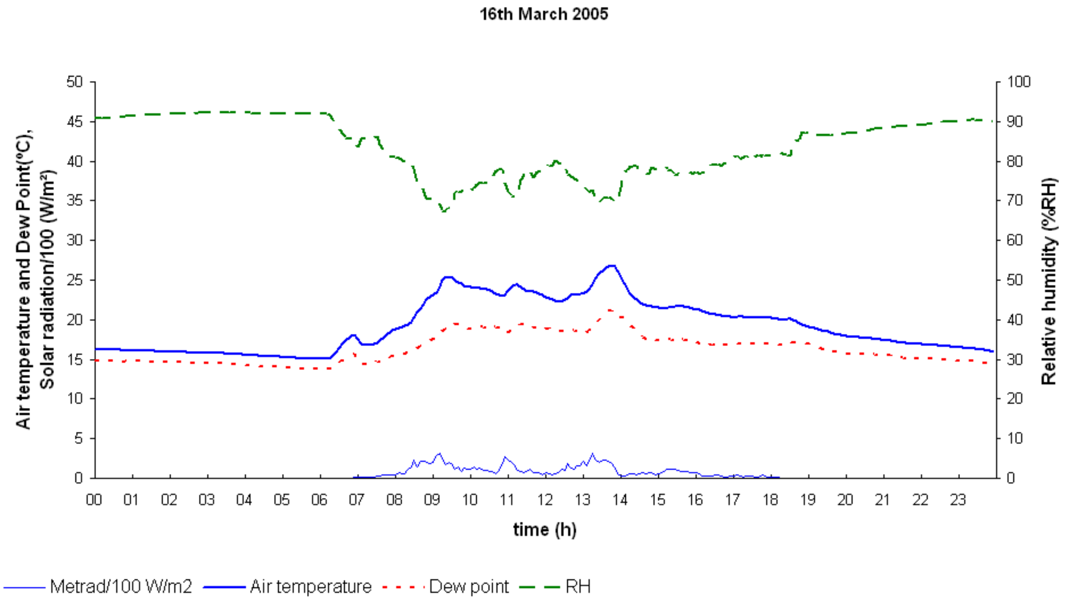


Figure 15. Measurements of RH, temperature and humidity within the crop canopy on a ‘cool’ day (i.e. where temperature credits were being used).

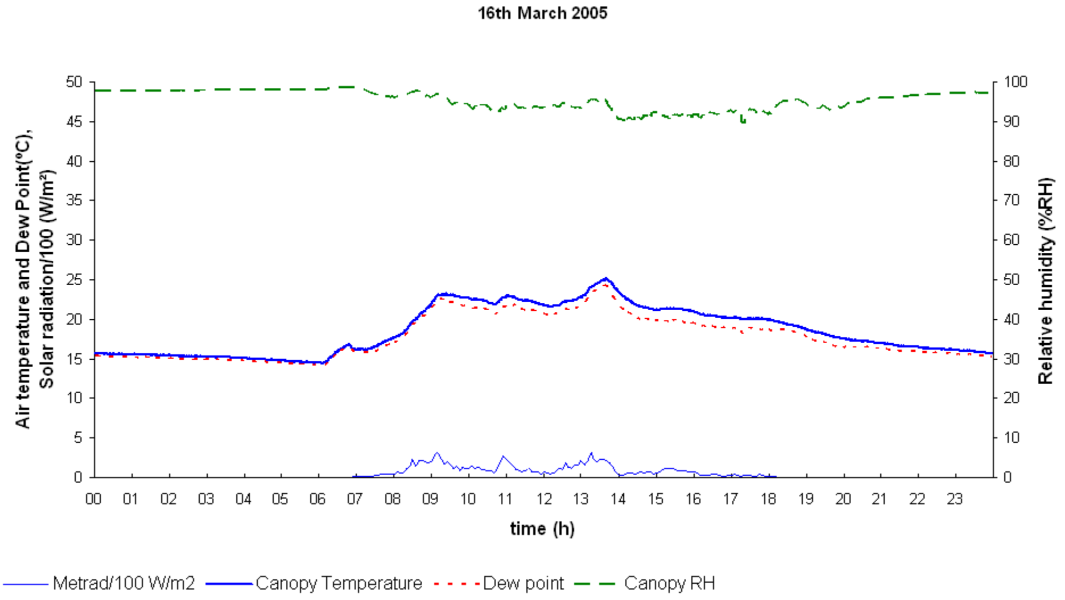


Figure 16. Measurements of RH, temperature and humidity at the aspirated screen on a high temperature day (i.e. heating and solar gain were contributing to achieved temperatures).

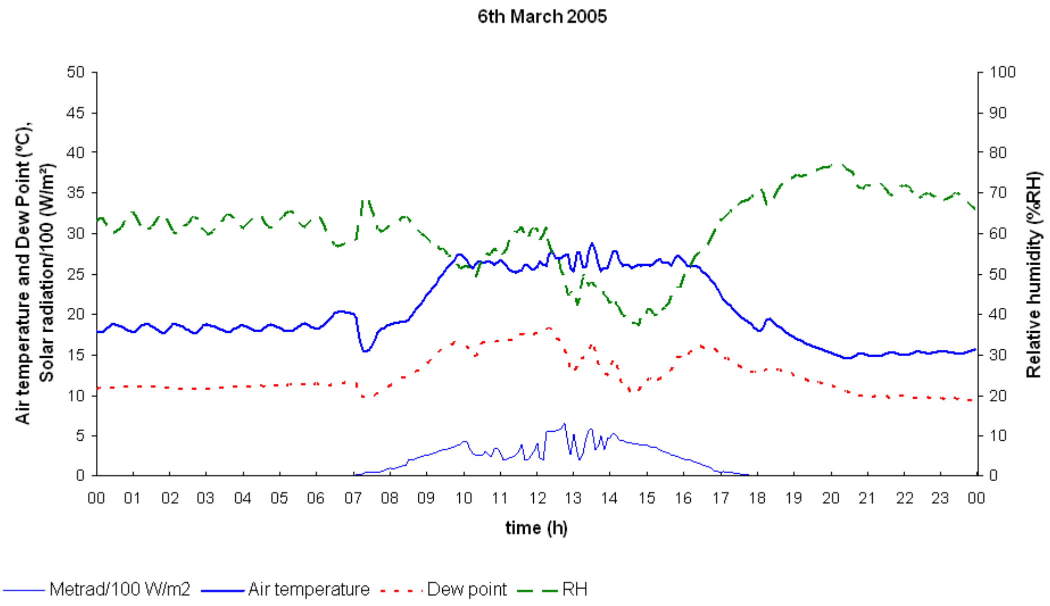
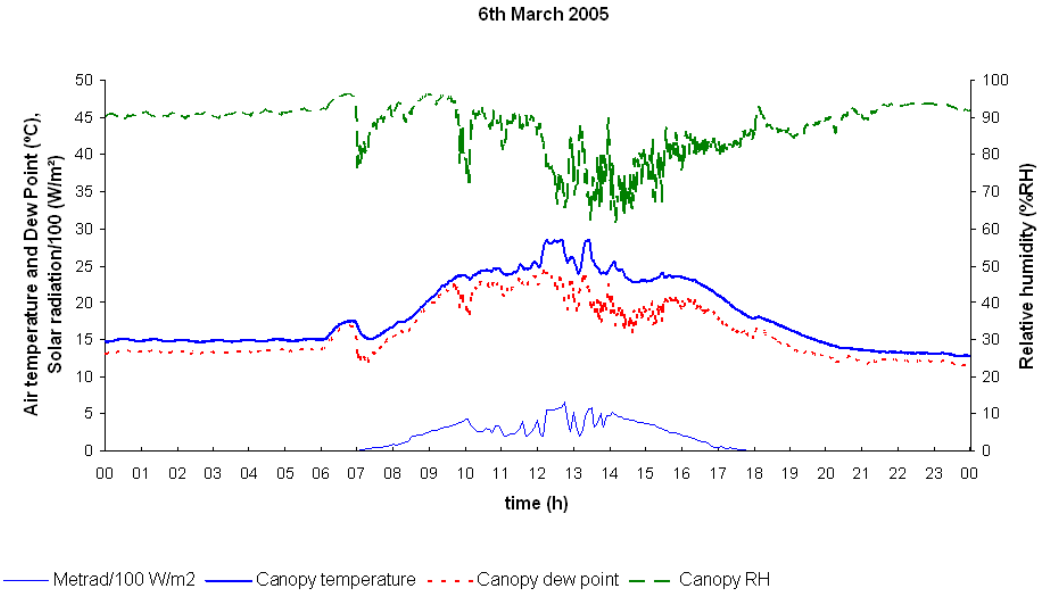


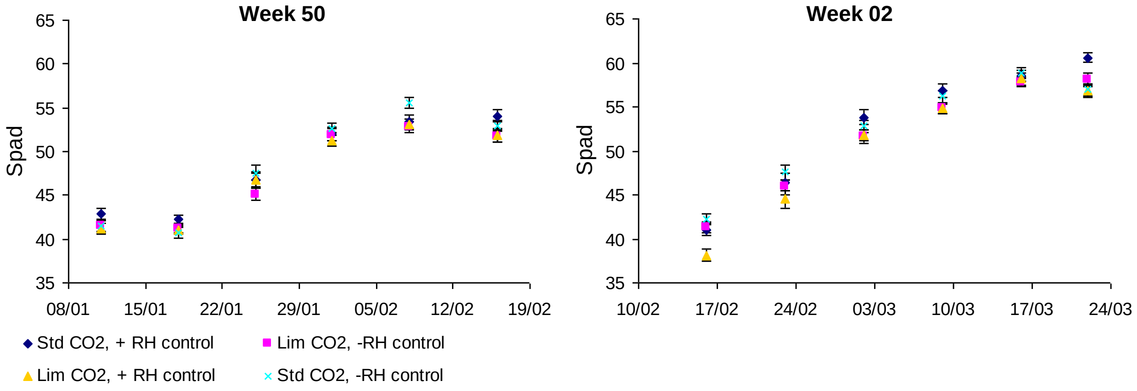
Figure 17. Measurements of RH, temperature and humidity within the crop canopy on a high temperature day (i.e. heating and solar gain were contributing to achieved temperatures).



2.3.2. Interim assessments

Foliage quality in both the upper and lower canopy was observed to be good for all treatments. Since there were no visual differences observed between treatments, leaf greenness was measured weekly during short days using a Spad meter in an attempt to quantify any subtle differences that may have occurred (figure 18). It is clear that greenness of the upper canopy increased with time until 1-2 weeks from marketing when no further increase occurred. There were however no significant differences in leaf greenness relating to either the humidity or CO_2 enrichment control treatments.

Figure 18. Leaf greenness of the upper canopy during short days for crops stuck in week 50 and week 02.



Despite regular inspections, and the challenging humidity levels achieved in some treatments, only one incidence of disease was noted. That is, in the week 02 stuck crop, Chrysanthemum white rust was recorded in one plot in the compartment with no humidity regulation and no CO_2 enrichment. It would not be valid to link this outbreak with the high humidity levels associated with this compartment from such an isolated incidence and it was outside of the remit of this project to investigate epidemiology. The outbreak affected 6 of the 24 pots in the plot and did not spread to plants in the adjacent plots on the same bench and was observed as plants reached maturity.

2.3.3. Assessments at marketing

There were no differences in the time taken to reach marketing stage 3 between treatments. However, all treatments received the same supplementary lighting treatments and achieved comparable average temperatures; hence differences in time to flowering would not be expected. The first three crops (stuck in weeks 40, 45 and 50) reached marketing stage 3 in an average of 58 short days and the last crop (stuck in week 02) was slightly faster at an average of 54 short days.

Visual inspection of treatments by both research staff and growers failed to identify any consistent visible differences between treatments at maturity as will be apparent from the comparative photographs included in Appendix 4. Detailed measurements of a range of parameters were made when pots reached marketing stage 3. In general these data support the visual observations made since there were few statistically significant differences noted in the data collected (full set given in Appendix 5. Minor differences found to be statistically significant are described in the following.

Levels of significance are indicated by the following symbols:

ns	not significant
*	P <0.05
**	P <0.01
***	P <0.001

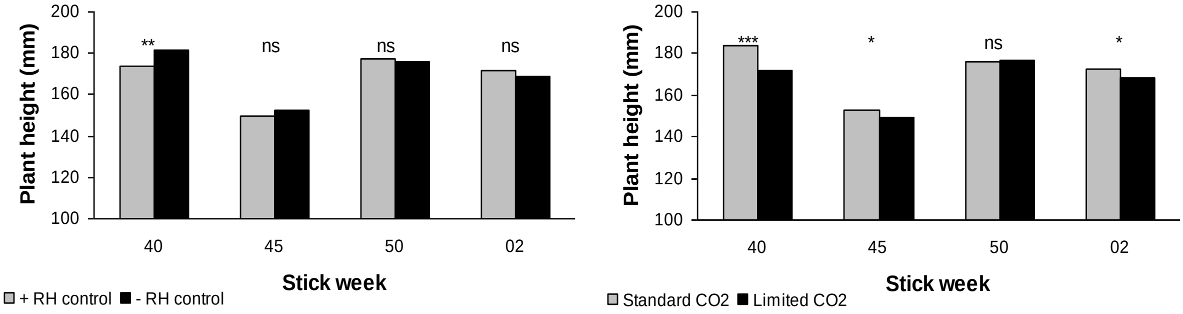
<u>Plant height</u>

Crops stuck in weeks 40, 50 and 02 all reached the marketing specification of 18cm to 22cm for plant height (Appendix 5). Irvine, Dark Swing Time and Energy Time stuck in week 45 were also close to the 18cm minimum height but the remaining varieties from the week 45 stick were 1 to 2 cm below the minimum height requirement. Since all varieties received at least one application of daminozide after pinching, there is scope to increase plant height for this stick week.

Plant height was significantly greater for the no RH control treatment than the standard RH control treatment for the week 40 crop (figure 13). This difference equates to a 4.5% or 1cm increase in plant height. Note height was measured from the pot rim to the base of the tallest flower per plant. Flowers would account for an extra 2cm of height when considering market specifications. There were no significant differences relating to RH control for the weeks 45, 50 or 02 crops. This links to the differences in achieved humidity levels in the treatments, which were most pronounced for the week 40 crop. It also seems likely that similar differences might normally occur for spring grown crops but unusually low outside temperatures coincided with about the middle 2 weeks of short days for the week 02 crop in this experiment which apparently resulted in smaller than expected differences between RH control treatments.

CO_2 had a greater effect on plant height with significantly taller plants associated with the standard enrichment treatment than the limited treatment for three of the four crops assessed (figure 19). For crops stuck in weeks 45 and 02 a 2.5 % height increase was recorded and for the crop stuck in week 40, plants were 7.3% taller on average as a result of receiving standard enrichment rather than limited enrichment.

Figure 19. Plant height at marketing in response to humidity control and CO_2 enrichment treatments.



Daminozide applications were made according to plant progress in relation to data tracked on a commercial nursery in previous years. All compartments were judged to have the same growth regulator requirements in this experiment. Requirements did vary with variety and also stick week (table 3).

Table 3. Number of Daminozide applications (as Dazide at 1.5 g/l) in short days for each sticking date and variety.

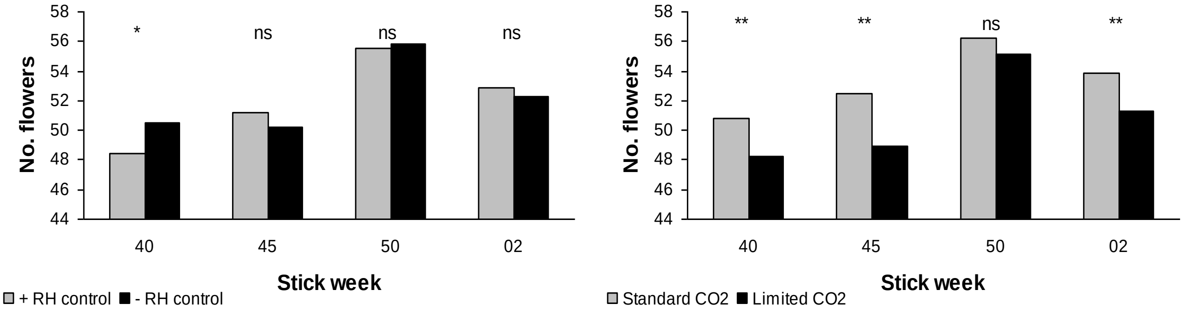
	Week 40	Week 45	Week 50	Week 02
Chesapeake	2	2	2	2
Covington	1	1	1	2
Dark Grace Time	1	1	1	1
Dark Swing Time	1	1	2	2
Energy Time	2	2	3	2
Irvine	2	2	3	3
Sockeye Time	1	1	1	1
Surf	2	2	2	2

<u>Number of flowers at stage 5 or above</u>

Either the higher achieved humidity levels associated with the no RH control treatment for the week 40 crop or the slight increase in achieved temperature was apparently beneficial to flowering with a slight (4%) increase of open flowers at marketing for this treatment (figure 14). This difference was not repeated for any of the other stick weeks, although as noted above, higher humidities may have been expected towards the end of production of the week 02 crop than were realised in the 2004/05 growing season.

Standard enrichment with CO_2 increased the number of flowers per pot by an average of 5-7% (3 flowers) for crops stuck in weeks 40, 45 and 02 (figure 20). The smaller (and non significant) differences between the treatments for the week 50 crop may be related to the smaller differences in achieved CO_2 concentrations between these treatments in general and in particular over the last week of production for this crop when flowers were developing.

Figure 20. Number of open flowers per pot at marketing in response to humidity control and CO_2 enrichment treatments

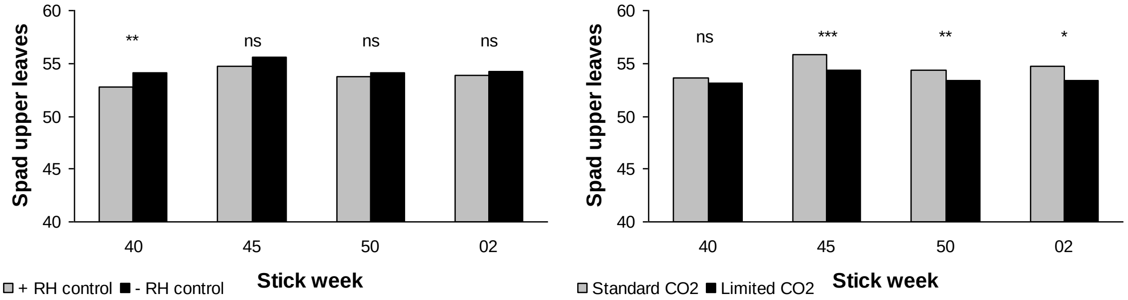


Leaf greenness

A slight increase in leaf greenness in the upper canopy was associated with the no humidity control treatment for the week 40 crop only (figure 21). Standard CO_2 enrichment also increased leaf greenness in the upper canopy for crops stuck in weeks 45, 50 and 02. It seems surprising however that this difference was not also significant for the week 40 stuck crop since this crop had one of the greatest differences in achieved CO_2 concentration. This discrepancy may be linked to the biological control programme. *Amblyseius cucumeris* predators in vermiculite were used on the week 40 crop which resulted in a significant amount of vermiculite on leaves at marketing. These deposits caused difficulties with recording leaf greenness. The formulation of *Amblyseius cucumeris* predators was changed to sachets in later crops to avoid this problem.

There were no consistent differences between treatments for lower canopy leaf greenness indicating that treatments has no influence over lower leaf quality.

Figure 21. Upper canopy leaf greenness in response to humidity control and CO_2 enrichment treatments



Plant weight

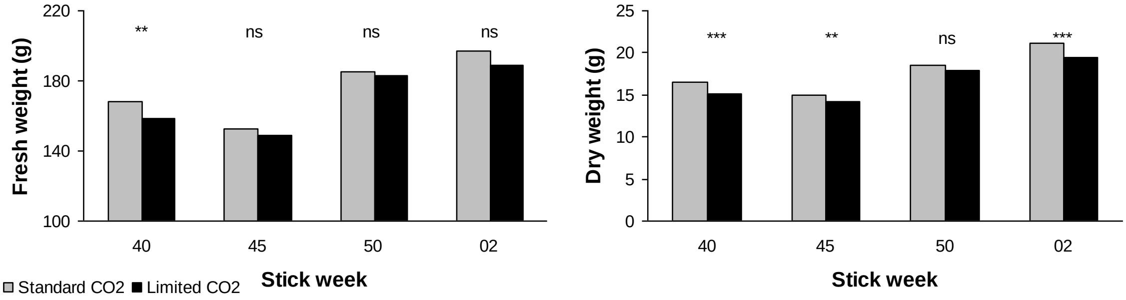
Standard CO_2 enrichment significantly increased fresh weight of the five plants in a pot in comparison with limited CO_2 enrichment for plants stuck in weeks 40 and 02 (figure 22).

Standard CO_2 enrichment significantly increased dry weight of the five plants in a pot in comparison with limited CO_2 enrichment for plants stuck in weeks

40, 45 and 02 by 9%, 6% and 9% respectively (figure 22). A similar trend was also noted for plants stuck in week 02 but this was not found to be significant.

Overall, where crops have accumulated and used the greatest number of temperature credits (i.e. the week 40 and 02 crops in particular), there was a resultant reduction in day time heat demand and greater limitation on CO_2 enrichment due to a lower heating requirement. These differences in plant weight would be of particular relevance to growers of spray chrysanthemum or other cut flowers graded according to stem weight.

Figure 22. Comparison of standard and limited CO_2 enrichment treatments on plant weight per pot at marketing.



<u>Mineral analysis</u>

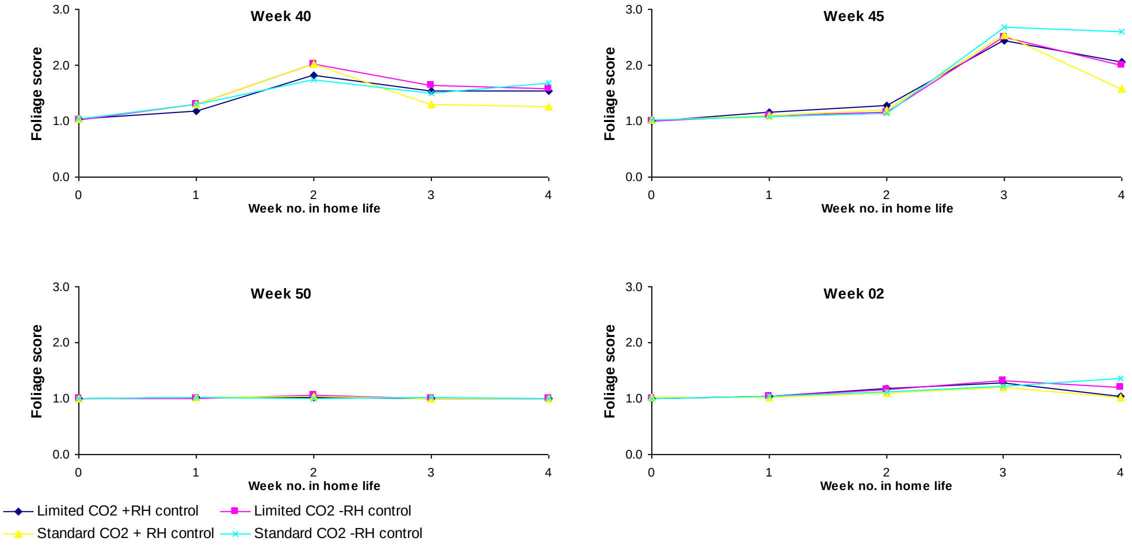
As with assessments of plant quality, there were no consistent differences between treatments linking compost or leaf tissue nutrient status with the humidity control or CO_2 enrichment treatments (appendix 5). Leaf mineral levels were generally within ranges considered to be acceptable for chrysanthemums indicating that adequate levels had been supplied via the compost and liquid feeding. Boron levels were low to undetectable in some cases in the compost and were also at the lower end of the acceptable range for leaf tissue, suggesting that the liquid feed used may benefit from the addition of micronutrients. For three of the four crops assessed (weeks 40, 45 and 50), leaf tissue N was slightly higher for the limited CO_2 treatments than the standard CO_2 treatments. Since plant dry weight was greater for the standard CO_2 enrichment treatments than the limited CO_2 treatments there is a suggestion that plants would benefit from an increase in N nutrition when growing more vigorously under full CO_2 enrichment. However this slight adjustment to the feed might be considered unjustified when both regimes produced comparable overall quality and leaf tissue N within the acceptable range.

2.3.4. Assessments in shelf life

Since treatments imposed had only subtle effects on plants at marketing it is perhaps as to be expected that treatments also had no effect on plants during shelf life (see appendix 6 for the full data set). The patterns of deterioration occurring in shelf life are illustrated in figures 23 and 24 as average data for the eight varieties over the duration of shelf life testing. Note week 0 of shelf life testing (i.e. when sleeves were removed), represents 12 days from marketing stage three due to the duration of the transport and store life phases prior to removing sleeves and commencing assessments.

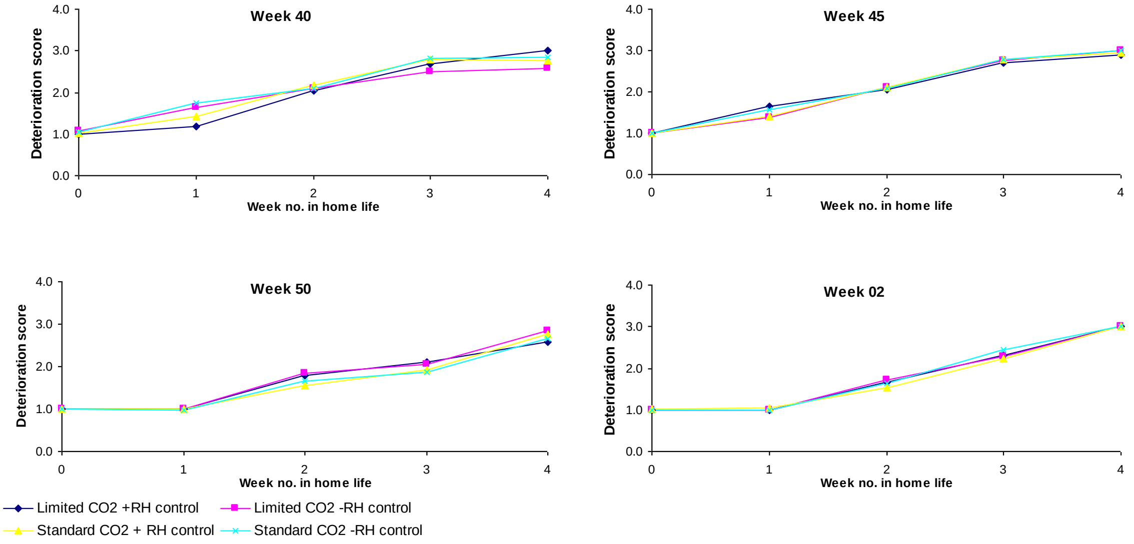
Foliage quality on the whole was good throughout shelf life, remaining close to score 1 (which is the score relating to all leaves green) for most of this time. Slightly lower quality was apparent for the first 2 crops (weeks 40 and 45) but even here, the highest average score did not exceed 3 (equivalent to half of the leaves green and half showing yellowing).

Figure 23. Foliage quality scores during shelf life.



Overall pot deterioration increased steadily with time for all treatments (figure 24), with the majority of pots reaching a score 3 by the end of the assessment period (i.e. 4 weeks of home life or 38 days from marketing). Rate of deterioration appeared similar for all stick weeks. Appendix 6 illustrates pot deterioration score 3 for each variety.

Figure 24. Overall pot deterioration scores during shelf life.



It should also be noted that significant levels of leaf, stem and bud/flower rot was observed on individual pots during shelf life. Some examples of symptoms are illustrated below:

Botrytis at leaf edges of Dark Swing Time as sleeves were removed:

Spread of *Botrytis* into stems of Covington 1 week from removing sleeves:

Spread of *Botrytis* into stems of Irvine 1 week from removing sleeves:

Occurrence of rotting did not appear to be related to any one treatment. Observations suggest the origin of this problem was where leaves/flowers were touching the sleeve and condensation formed at the point of contact. This then formed a suitable infection site for botryis. In severe cases, this rot then spread to stems resulting in death of all material above the stem lesion. Incidence of rotting was recorded via counts of rotted leaves, buds and flowers each week until either one whole plant or 40 rotted leaves had been recorded on one plant. At this point the plant was considered to have finished its useful shelf life. This problem appears to be a result of the long period of sleeving, however this period is considered a realistic representation of current supply chains that pot chrysanthemums would be distributed through. The causes of this problem and means of preventing it may warrant further attention.

2.4. Discussion

The detailed environmental monitoring carried out within this trial has highlighted some interesting changes that occur when compartments are controlled by temperature integration and are using temperature credits.

Achieved 24 hour average temperature was very close to set point in this experiment, despite the high vent set point temperature used (i.e. 26°C or 7.5°C above set point). This agrees with comments made in the final report for PC 190 which compared temperature integration strategies with conventional temperature control. With conventional temperature control, achieved average temperature is often above set point temperature because there is no drop in temperature to compensate for solar gain which can increase day temperature. Since temperature credits are only likely to be accumulated during the day over the winter period of this experiment, temperature integration may also be expected to give an ongoing difference between day and night temperatures. This was observed in this experiment (figure 3), with day temperature 2.8 to 3.2 °C higher than the night.

When air temperature was allowed to drop below the set point level of 18.5°C, RH increased. However standard strategies to alleviate this problem, i.e. the use of blackout gapping, venting and then pipe heating, were effective in controlling RH below the 85% threshold set in this experiment. It is therefore not necessary to suffer a substantial rise in RH simply because temperature integration is being used.

This then leads on to questions of energy use. The current project was not designed to prove that temperature integration can save energy; this has already been established within other projects (e.g. PC 190, PC 197). However the impact of treatments on energy use is of interest. In this experiment, heat energy consumption was monitored for each compartment and when pipe heat was used to reduce RH, more energy was consumed. This is of greatest relevance to crops grown in autumn and spring, when solar gain provides a greater contribution to the maintenance of average temperature rather than in the depths of winter when there is greater use of the boiler for heating which automatically reduces RH. Obviously where RH is reduced, the greater the energy savings will be. To fully optimise energy savings one therefore needs to establish the risks associated with allowing higher RH levels than are currently tolerated. It is outside of the scope of this project to examine the disease implications of allowing higher than normal levels of RH, although this work is being addressed within the Defra project HH3611SPC at Warwick HRI. Two pieces of information established within this project should however be of interest to the issue of disease risk.

Firstly, environmental monitoring has demonstrated that canopy RH is significantly higher than aspirated screen RH. During a period of high aspirated screen RH and low air temperature, dew point temperature remained just above leaf temperature suggesting no leaf surface wetness despite the high (97%) RH levels recorded. This raises the issue of where RH should be monitored which again is to be addressed within the Defra project HH3611SPC.

Secondly, an isolated outbreak of chrysanthemum white rust did occur at the end of this experiment (i.e. within the week 02 crop). A patch of 8 pots were found to have visible symptoms in this outbreak which was spotted as plants reached marketing stage 3. The outbreak was found in one of the no humidity control compartments but it would not be valid to assume that this was a result of the high achieved humidity levels because there was no similar outbreak in the second no humidity control compartment for the same batch of plants (i.e. originating from the same batch of cuttings). It would however have been of interest to have had a further crop with a later sticking date (e.g. week 05) to see if growth in spring with greater expected accumulation of temperature credits would have suffered greater effects than those recorded here.

The main objective of the standard and no humidity control treatments within this project was to evaluate potential implications for plant quality. In this respect there is apparently no risk in terms of commercial plant quality in minimising the amount of energy used to control RH. Plants from all stick weeks were considered to have no significant differences in terms of commercial quality in relation to humidity control treatments. This may be due to the fluctuations in achieved RH levels noted. While no RH control resulted in high (90%+) aspirated screen humidity, this lasted for only short periods of time, followed by periods below the 85% threshold level. This is reflected in the average achieved humidity data presented in figure 5.

In the most extreme case, high achieved night time humidity exceeded the 85% threshold in the no humidity control treatments during the first three weeks of short days for the week 40 stuck crop. Achieved average RH then dropped for the remaining short day period of this crop as heat use increased with the onset of lower outside temperatures. Hence whilst high RH may be expected to have a negative impact on plant quality, in practise RH levels are fluctuating and it may be this fluctuation has helped to minimise the impact.

The feeling by growers that the use of temperature integration would limit achieved CO_2 concentration when using boiler flue gases without a heat store was also verified by environmental data collected. Differences in achieved

CO_2 concentration were found throughout the experiment between standard CO_2 enrichment and enrichment limited to represent supply from boiler flue gases without a heat store. These differences were greatest during the early and later stages of the experiment which coincided with periods of greatest solar gain and hence higher accumulation and use of temperature credits. As may be expected, this reduction in available CO_2 resulted in a statistically significant decrease in dry matter accumulation, with the greatest effects found for the week 40 and week 02 crops. This also impacted on factors such as number of open flowers per pot and plant height. However despite the statistically significant differences recorded, it was clear that plant quality in the limited CO_2 enrichment treatments was not significantly different from that in the standard CO_2 enrichment treatments in commercially relevant terms. Hence whilst differences noted are of scientific interest they would not be expected to be of commercial relevance.

It would however be wise to monitor this impact on cut flower crops graded by weight which are grown either side of the main winter period when greater accumulation of temperature credits would be expected and hence availability of CO_2 from flue gases more severely limited. It is also worth noting here that the standard CO_2 enrichment strategy used in this experiment represents best practise and may represent higher achieved CO_2 concentrations than may currently be expected on many commercial nurseries. Hence the limitation of Ti on CO_2 availability may be less severe in practise than has been demonstrated here.

Analysis of CO_2 use and availability for the different energy supply scenarios showed that for the majority of the trial period more CO_2 would have been available than was actually used. At face value this suggests that the limited CO_2 treatments could have achieved higher CO_2 levels even with the boiler with no heat store scenario. However closer investigation shows that when CO_2 was available i.e. there was a demand for heat, the target of 1000ppm was easily reached and the surplus CO_2 would simply have been rejected to the boiler chimney. A typical daytime CO_2 level in the limited CO_2 enrichment treatments would have shown:

- High CO_2 during the early part of the day when the blackout screens were drawn back creating a brief demand for heat.
- Low CO_2 level during the middle of the day as heat demand is low if not zero.
- An increase in CO_2 level towards the end of the day prior to the screens being drawn over as the outside temperature and light levels fall and heat demand increases once again.

Figure 25 shows a typical CO_2 profile over a 24 hour period in one of the limited CO_2 enrichment treatments (starting with the start of the night period at 18:00 hrs). In this case there was no heat demand towards the end of the day. It can be seen that CO_2 enrichment occurred just after 06:00, again at around 08:20 when the level fell below 1000ppm. CO_2 levels then fell as no more CO_2 was available for the remainder of the day. Periods of heating are also included in this graph to illustrate periods where CO_2 enrichment was enabled because the compartment was considered to be using the boiler to supply heating (i.e. when pipe temperature was 3°C or more above air temperature). For this reason the axis for temperature difference has been set to start at 3°C (i.e. the smallest difference that would allow CO_2 enrichment to take place).

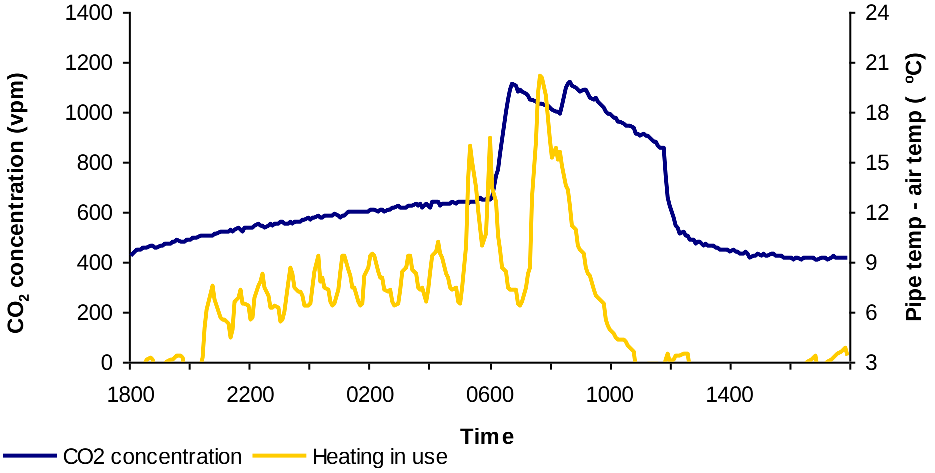


Figure 25. Daily CO_2 profile in a limited CO_2 enrichment treatment

Peak CO_2 use in the unlimited CO_2 treatment was in week 43 at almost 0.25kg/m^2 per week. For a boiler based heat supply system this equates to a heat demand of 1.3kWh/m^2 per week (0.18kWh/m^2 per day). The standard RH control treatment used 2.8kWh/m^2 per week during this period and the no RH control treatment used 0.36kWh/m^2. Therefore a boiler with an appropriately sized heat storage system would have been able to supply all the required CO_2 without having to destroy heat. The size of heat store required to store the equivalent of 0.18kWh/m^2 would be 32.4m^3/Ha.

CO_2 use during the majority of the trial period was low because it was during the winter and only small amounts of venting were required. Weeks 11 & 12 demonstrated what can happen as soon as weather conditions improve. CO_2 use increased as the amount of venting increased but the amount of CO_2 available rapidly fell as heat demand reduced. By week 12 the heat demand associated with the standard RH control treatment was barely sufficient to satisfy the CO_2 use even if it had all been provided by CHP. However the contribution of the supplementary lighting to greenhouse heat demand should not be underestimated. Generally speaking, once outside the trial period lighting is used to a lesser extent as natural light levels are higher. Therefore as the use of supplementary lighting decreases, pipe heat will tend to increase, compensating to some extent for the increased CO_2 demand.

Since the treatments evaluated in this experiment had no impact on the commercial quality of plants at marketing, it is of little surprise that there were similarly no significant differences identified between treatments during shelf life testing. The most notable feature of the shelf life assessments was the incidence of *Botrytis* which, when associated with stem infections, often resulted in the loss of branches or even whole plants. These infections largely became apparent when sleeves were removed from plants and when the first shelf life assessment was made. New infections after removal of sleeves were rare and infections limited to leaf margins rarely spread once sleeves were removed. Clearly the shelf life simulation used in these assessments was very testing, especially in relation to the prolonged period that plants spent in sleeves (12 days in total). Whilst this regime appears justified in relation to the current supply chain and expected life on the store shelf, it is more severe than earlier shelf life testing procedures such as those followed in PC 13c from which guidance to stores on degree of flower opening required during the winter sales period was issued. Discussion surrounding this issue with industry representatives suggested that while breeders and growers who supply retail outlets all routinely test their products for keeping quality, the parameters used within this testing do vary. This issue does warrant further attention both in terms of identifying a standard testing procedure that all growers should follow and in terms of evaluating how best to minimise the impact of *Botrytis* can have when plants are sleeved and conditions for *Botrytis* infection are likely to be favourable.

2.5. Conclusions

- Good quality pot chrysanthemums **can** be produced during the UK winter period under supplementary lighting using temperature integration.

- Differences in achieved RH and CO_2 concentrations did result from the treatments applied but had no significant impact on final commercial quality. There is a suggestion that these influences may have greater impact earlier in the autumn and later in spring than the current experimental period covered.

- Achieved 24 hour average temperatures were very close to the 18.5°C set point; despite the high (26°C) vent set point used. On average, achieved day temperature was 3 to 4°C higher than achieved night temperature.

- During periods when temperature credits were being used and air temperature was allowed to fall below conventional set point temperature, RH levels increased.

- Standard settings available in environmental control computers can be used to successfully control humidity below a threshold value when running temperature integration. These settings do however increase energy consumption (by up to 10% in this experiment) and need to be targeted carefully in order to fully optimise energy savings. Ongoing Defra work is addressing these issues in relation to chrysanthemum white rust and *Botrytis*.

- On average, during the period between week 43 and week 12 the standard RH control treatment required an extra 7.5kWh/m^2 of heat as hot water. Equivalent to 8.8kWh/m^2 of gas and 8% of the total heating energy used.

- Canopy RH measurements were significantly higher than aspirated screen RH. In ‘cool’ conditions (i.e. when air temperature dropped below conventional set point temperature), canopy RH was 97% and above compared with around 91% on ‘warmer’ days.

- Canopy dew point temperature was closer to leaf temperature during periods of high canopy RH compared with lower canopy RH. Dew point temperature did not exceed leaf temperature in either of these conditions for the spot measurements taken but there is potential for this to occur given the closeness of these temperatures under extreme conditions.

- Increases in achieved RH levels had no visible impact on final plant quality or longevity in shelf life.

- Chrysanthemum white rust occurred at the end of the experiment in a localised position. The outbreak was such that it would not be valid to speculate about how it may have been related to environmental conditions.

- High RH levels were achieved in the no RH control treatment but had little impact on either plant quality or incidence of lower leaf loss due to *Botrytis* when maintaining high standards of glasshouse hygiene.

- Achieved CO_2 concentrations in treatments representative of a nursery using boiler flue gases in conjunction with temperature integration, were 300 to 400 vpm lower than in standard CO_2 enrichment treatments (which were more representative of a nursery using heat storage).

- During the majority of the trial period CO_2 use in the standard CO_2 enrichment treatment would have been easily supplied by the associated heat demand on a boiler with heat storage.

- Although there was adequate CO_2 produced during the day without heat storage for the main winter period, the addition of a heat store will extend the duration over which enrichment can be used to periods with higher incident light intensities and therefore much to gain from enrichment.

- Limiting CO_2 enrichment significantly reduced plant dry weight by 6 to 9% and flower number by 5-7%. These differences were however judged to be insignificant commercially.

- Limiting CO_2 enrichment also had no significant impact on pot longevity in shelf life.

3. Acknowledgements

Our thanks go to Cleangro Ltd and Yoder Toddington Ltd for the supply of cuttings for this project. We are also grateful to the advice and support of the members of the AYR CGA technical committee namely, Mr Dave Abbott, Dr Ruth Finlay, Mr Mike Holmes and Mr John Phillips. Key members of staff who also deserve thanks for their valuable inputs and who are not mentioned elsewhere in this report include Rodney Edmonson, David Hart, Ann Mariott, Alan Morgan and Peter Watson.

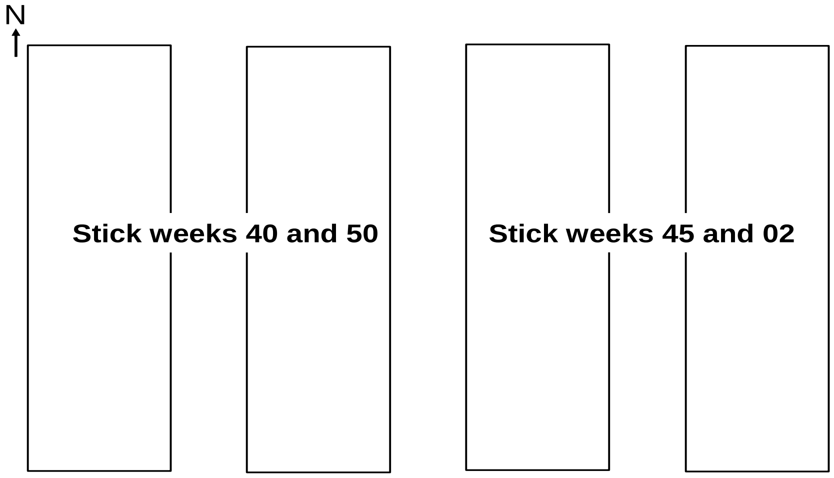
Appendix 1 – Experimental plan:

All plants were propagated and given long days in compartment B1 of B Block.

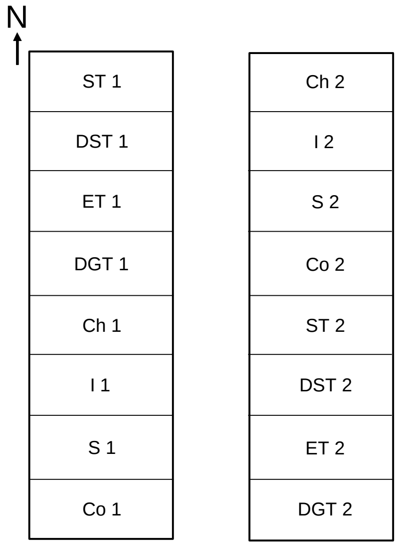
Treatments during short days were imposed in a 2 x 2 factorial experiment covering 2 humidity regimes and 2 CO_2 enrichment regimes, combined in four compartments of B Block as follows:

B5: +RH control and Standard CO_2 enrichment.
B6: -RH control and Limited CO_2 enrichment.
B7: +RH control and Limited CO_2 enrichment.
B8: -RH control and Standard CO_2 enrichment.

Two plots each of eight varieties of pot chrysanthemum were grown in each environment with 2 benches allocated for each of the four sticking dates as follows:



Varieties were allocated to benches to give a complete replicate set on each bench, randomised for trend effects down the bench:



Key

ST	Sockeye Time
DST	Dark Swing Time
I	Irvine
S	Surf
DGT	Dark Grace Time
ET	Energy Time
Ch	Chesapeake
Co	Covington

Each plot consisted of 4 rows of 6 pots per row. Rows were staggered. This gave 10 fully guarded rows in each plot as illustrated below:

```
G       G        G       G       G        G
    T        T       T       T       T        G
G       T        T       T       T        T
    G        G       G       G       G        G
```

Where: G = guard pot and T = treatment pot.

Appendix 2 – Breakdown of Scotts growing medium (Longfield Mix)

- Irish Sphagnum moss peat:
    - 30% 0-10mm
    - 30% 6-12mm
    - 20% 10-25mm
    - 20% composted pine bark 0-8mm

- 3 kg/m^3 Dolodust

- pH 5.5 to 5.8

- Starter fertiliser providing:

NO_3-N	107 mg/l
NH_4-N	73 mg/l
P	150 mg/l
K	299 mg/l

- Wetting agent

- Intercept 5GR at 280 g/m^3

- Terrazole 35 WP at 40 g/m^3

- Bulk density 280 g/l (approximately)

- Conductivity 250-340 µs per cm

- Moisture content 65-75%

Appendix 3 – Crop diary.

DATE	CROP	COMMENTS
30/09/04	Week 40	Stuck cuttings and treated with Bumper 250 EC at 0.4ml/l.
30/09/04	Week 40	Drenched cuttings with Nemasys f
10/10/04	Week 40	Removed sheets late pm
12/10/04	Week 40	Sprayed Dazide at 1.5g/l to cuttings
18/10/04	Week 40	Moved cuttings to short day compartments at intermediate spacing (25 pots/m^2)
25/10/04	Week 40	Pinched cuttings
27/10/04		Applied Panacide under benches under capillary matting for *Sciarid/Scatella* control
02/11/04	Week 40	Moved pots to final spacing (14.5 pots/m^2)
04/11/04	Week 45	Stick cuttings and treat with Bumper 250 EC at 0.4ml/l.
04/11/04	Week 45	Drenched cuttings with Nemasys f & applied *Hypoaspis miles*
05/11/04	Week 40	Applied Dazide at 1.5g/l to all varieties
10/11/04	Week 40	Sprayed Majestik at 25ml/l for shore flies & thrips
11/11/04	Week 40	Introduced *Amblyseius cucumeris* (bran free) at 200/m^2
12/11/04	Week 40	Applied Dazide at 1.5g/l to Chesapeake, Energy Time, Surf & Irvine
14/11/04	Week 45	Removed sheets late pm
17/11/04		Introduced *Phytoseiulus* at 10 mites per sqm for red spider mite
17/11/04	Week 40	Introduced *Amblyseius cucumeris* (bran free) at 200/m^2
17/11/04	Week 45	Applied Dazide at 1g/l to cuttings
22/11/04	Week 45	Moved pots to short day compartments at 25 pots/m^2
24/11/04		Introduced phytoseiulus for red spider mite
24/11/04		Introduced *Amblyseius cucumeris* at 200/m^2
24/11/04		Sprayed Talstar at 0.4ml/l red spider mite control around compartment edges
30/11/04	Week 40	Applied Dazide at 1.5g/l tto Energy Time & Irvine
30/11/04	Week 45	Pinched Covington, Chesapeake, Surf, Energy Time, Irvine Dark Swing Time
01/12/04		Introduced *Amblyseius cucumeris* bran free b5, 6, 7 & 8
02/12/04	Week 45	Pinched Dark Grace Time, Sockeye Time.
06/12/04	Week 45	Applied Dazide at 1.5g/l to all vars
07/12/04	Week 45	Moved pots to final spacing (14.5 pots/m^2)
08/12/04		Introduced *Amblyseius cucumeris* (bran free formulation)
09/12/04	Week 50	Stick cuttings and treat with Bumper 250 EC at 0.4ml/l.
09/12/04	Week 50	Applied *Hypoaspis miles* & drenched with Nemasys f.
19/12/04	Week 50	Removed sheets late pm
22/12/04	Week 45	Applied Dazide at 1g/l to all wk 50 cuttings b1
22/12/04		Introduced *Amblyseius cucumeris* at 1 sachet/m^2
22/12/04		Introduced *Phytoseiulus* for red spider mite at 10 mites/m^2
27/12/04	Week 50	Moved pots to short day compartments at 25 pots/m^2
04/01/05	Week 50	Pinched Chesapeake, Covington, Dark Grace Time and Sockeye Time.
05/01/05		Sprayed Talstar at 0.4ml/l red spider mite control around compartment edges
05/01/05	Week 50	Pinched Irvine and Dark Grace Time
07/01/05	Week 50	Pinched Surf & Dark Swing Time
10/01/05	Week 50	Moved pots to final spacing (14.5 pots/m^2)
13/01/05	Week 02	Stuck cuttings and treated with Bumper 250 EC at 0.4ml/l.
13/01/05		Drenched cuttings with Nemasys f
21/01/05		Applied Panacide under benches under capillary matting for *Sciarid/Scatella* control

23/01/05	Week 02	Removed sheets late pm
26/01/05	Week 02	Sprayed all varieties with Dazide at 1g/l.
26/01/05	Week 50	Sprayed Dazide at 1.5g/l to Surf, Irvine, Energy Time & Chesapeake
31/01/05	Week 02	Moved pots to short day compartments at 25 pots/m^2
02/02/05		Introduced *Amblyseius cucumeris* at 1 sachet/m^2
02/02/05		Introduced *Phytoseiulus* for red spider mite at 10 mites/m^2
04/02/05	Week 50	Applied Dazide at 1.5g/l to Dark Swing Time, Irvine & Energy Time
07/02/05	Week 02	Pinched Covington, Chesapeake, Surf, Energy Time & Dark Swing Time
08/02/05	Week 02	Pinched Irvine
09/02/05	Week 02	Pinched Dark Grace Time, Sockeye Time.
11/02/05	Week 02	Sprayed Dazide at 1.5g/l to all varieties
14/02/05	Week 02	Moved pots to final spacing 14.5 pots/m^2
23/02/05	Week 02	Applied Dazide at 1.5g/l to Energy Time, Irvine, Surf, Chesapeake & Covington
03/03/05		Applied Panacide under benches under capillary matting for *Sciarid/Scatella* control
04/03/05		Introduced *Phytoseiulus* for red spider mite at 10 mites/sqm
04/03/05		Introduced *Amblyseius cucumeris* at 1 sachet/m^2
11/03/05	Week 02	Applied Dazide at 1.5 g/l to cvs Dark Swing Time, Irvine & Energy Time
30/03/05	Week 02	Sprayed Bumper 250 at 0.4ml/l on all pots in compartment with white rust infection
31 /03/05	Week 02	Incinerated plant material infected with white rust

Appendix 4 – Photographic comparisons of treatments at marketing stage 3

Chesapeake

Limited CO_2 - RH control	Limited CO_2 + RH control	Standard CO_2 - RH control	Standard CO_2 + RH control

Covington

Limited CO_2 - RH control	Limited CO_2 + RH control	Standard CO_2 - RH control	Standard CO_2 + RH control

Dark Grace Time

Limited CO_2 - RH control	Limited CO_2 + RH control	Standard CO_2 - RH control	Standard CO_2 + RH control

Dark Swing Time

Limited CO_2 - RH control	Limited CO_2 + RH control	Standard CO_2 - RH control	Standard CO_2 + RH control

Energy Time

Limited CO_2 - RH control	Limited CO_2 + RH control	Standard CO_2 - RH control	Standard CO_2 + RH control

Irvine

Limited CO_2 - RH control	Limited CO_2 + RH control	Standard CO_2 - RH control	Standard CO_2 + RH control

Sockeye Time

Limited CO_2 - RH control	Limited CO_2 + RH control	Standard CO_2 - RH control	Standard CO_2 + RH control

Surf

Limited CO_2 - RH control	Limited CO_2 + RH control	Standard CO_2 - RH control	Standard CO_2 + RH control

Appendix 5 – Data collected at marketing stage 3.
Plant height (mm) from pot rim to base of upper most flower per plant.*

Stick week 40	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	162.8	159.2	180.4	166.6
Covington	173.2	154.0	189.7	168.5
Dark Grace Time	165.4	164.6	194.6	171.7
Dark Swing Time	179.9	172.8	186.1	187.8
Energy Time	185.1	177.3	173.2	190.0
Irvine	193.3	186.7	209.1	196.9
Sockeye Time	154.4	150.9	164.5	162.4
Surf	187.2	173.3	200.2	182.8

Stick week 45	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	135.8	135.3	142.7	136.9
Covington	141.9	143.5	156.8	146.4
Dark Grace Time	138.4	140.5	147.3	142.9
Dark Swing Time	171.2	167.0	175.0	170.0
Energy Time	160.5	156.4	164.6	154.7
Irvine	156.7	157.9	160.9	161.2
Sockeye Time	141.1	142.4	145.8	142.5
Surf	151.4	144.6	147.0	151.6

Stick week 50	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	171.1	170.5	170.9	172.9
Covington	164.6	166.6	161.6	167.6
Dark Grace Time	176.6	175.1	176.1	177.7
Dark Swing Time	188.5	182.5	178.5	182.7
Energy Time	191.3	184.3	184.0	194.3
Irvine	187.3	180.4	175.4	190.6
Sockeye Time	168.8	166.3	166.1	162.6
Surf	176.4	174.4	174.0	183.6

Stick week 02	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	156.9	157.4	160.3	163.9
Covington	141.2	144.7	150.9	152.0
Dark Grace Time	167.0	171.1	169.9	175.2
Dark Swing Time	193.7	196.6	192.0	194.3
Energy Time	177.3	172.8	185.4	187.1
Irvine	167.9	168.1	171.8	178.0
Sockeye Time	164.4	170.4	168.0	170.5
Surf	164.4	167.6	167.2	177.9

*For total height of plant, add 2cm for average height from base to top of flower.

Number of short days to marketing stage 3.

Stick week 40	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	58.6	58.4	58.7	58.6
Covington	55.8	55.0	56.3	55.2
Dark Grace Time	61.0	60.9	60.3	60.5
Dark Swing Time	60.0	60.0	60.2	60.0
Energy Time	58.1	58.6	58.5	59.3
Irvine	56.6	57.4	55.8	57.6
Sockeye Time	60.5	60.2	60.3	60.2
Surf	57.4	56.4	57.4	56.6

Stick week 45	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	58.1	59.3	58.6	58.7
Covington	53.1	55.0	53.7	55.2
Dark Grace Time	59.2	59.2	58.9	58.1
Dark Swing Time	59.5	59.8	59.5	59.9
Energy Time	56.7	57.9	57.4	56.8
Irvine	54.6	56.9	56.3	56.0
Sockeye Time	58.2	59.0	58.4	58.8
Surf	56.9	57.5	57.9	57.5

Stick week 50	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	57.9	57.3	57.3	57.8
Covington	54.3	54.0	55.1	54.8
Dark Grace Time	57.9	58.7	58.7	58.4
Dark Swing Time	60.9	60.5	60.1	61.4
Energy Time	57.1	56.7	56.8	57.2
Irvine	55.5	56.2	56.3	55.6
Sockeye Time	58.6	58.7	58.8	57.9
Surf	59.1	58.7	58.7	58.0

Stick week 02	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	55.0	55.1	55.1	55.1
Covington	51.4	52.3	52.1	51.6
Dark Grace Time	55.1	55.1	55.1	55.1
Dark Swing Time	56.7	56.7	56.7	56.7
Energy Time	52.1	52.5	52.5	52.5
Irvine	51.7	52.3	52.6	53.2
Sockeye Time	56.0	56.0	56.0	56.0
Surf	52.8	53.0	53.0	53.2

Plant diameter across 5 plants per pot (mm) – average of two measurements taken across the top of the pot canopy

Stick week 40	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	298	295	309	306
Covington	315	306	334	318
Dark Grace Time	298	303	315	300
Dark Swing Time	300	294	295	303
Energy Time	305	309	308	304
Irvine	330	324	337	325
Sockeye Time	289	292	291	296
Surf	357	325	350	340

Stick week 45	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	297	291	292	297
Covington	325	325	326	320
Dark Grace Time	303	291	293	301
Dark Swing Time	329	326	322	315
Energy Time	318	315	303	314
Irvine	326	342	314	335
Sockeye Time	319	310	301	310
Surf	345	346	325	345

Stick week 50	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	332	324	312	326
Covington	341	339	335	339
Dark Grace Time	324	343	328	323
Dark Swing Time	339	336	325	339
Energy Time	321	326	339	322
Irvine	362	352	345	352
Sockeye Time	326	336	333	318
Surf	355	355	353	340

Stick week 02	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	308	299	288	289
Covington	331	315	304	330
Dark Grace Time	280	282	288	285
Dark Swing Time	294	295	287	283
Energy Time	297	286	287	291
Irvine	328	316	307	306
Sockeye Time	278	290	282	277
Surf	294	284	277	284

Number of open flowers per pot.

Stick week 40	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	47	43	48	45
Covington	45	41	50	46
Dark Grace Time	60	60	61	61
Dark Swing Time	47	43	44	47
Energy Time	48	47	46	48
Irvine	62	54	65	60
Sockeye Time	49	46	49	52
Surf	42	41	45	45

Stick week 45	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	42	43	46	45
Covington	43	45	46	51
Dark Grace Time	57	54	58	59
Dark Swing Time	44	43	47	49
Energy Time	60	62	63	63
Irvine	56	59	65	68
Sockeye Time	42	46	48	47
Surf	44	43	41	44

Stick week 50	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	50	45	48	46
Covington	56	55	55	54
Dark Grace Time	61	66	67	65
Dark Swing Time	44	47	45	50
Energy Time	62	64	65	64
Irvine	74	72	76	74
Sockeye Time	51	51	51	52
Surf	44	43	44	44

Stick week 02	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	50	45	46	51
Covington	57	61	67	66
Dark Grace Time	59	59	61	63
Dark Swing Time	45	46	48	47
Energy Time	54	52	59	55
Irvine	58	65	63	67
Sockeye Time	44	50	50	47
Surf	39	36	36	37

Average Spad reading on upper leaves.

Stick week 40	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	49.32	48.31	49.07	50.28
Covington	52.10	51.16	54.61	52.96
Dark Grace Time	53.94	53.07	52.28	53.42
Dark Swing Time	54.81	52.37	53.99	54.49
Energy Time	57.14	59.06	57.28	60.91
Irvine	56.83	50.82	54.37	52.63
Sockeye Time	48.32	48.02	47.96	48.29
Surf	59.53	55.60	58.41	57.34

Stick week 45	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	53.30	49.10	51.60	51.68
Covington	56.73	53.67	56.30	55.08
Dark Grace Time	53.81	53.23	55.61	54.97
Dark Swing Time	58.16	55.64	56.74	56.54
Energy Time	59.06	58.23	63.10	62.79
Irvine	51.58	51.66	53.84	55.32
Sockeye Time	50.98	49.26	50.45	50.59
Surf	58.10	57.33	59.49	59.72

Stick week 50	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	47.77	46.75	49.27	47.23
Covington	52.38	52.19	52.75	54.50
Dark Grace Time	51.74	54.51	54.60	53.88
Dark Swing Time	58.92	58.97	58.73	60.96
Energy Time	54.02	53.33	57.40	54.97
Irvine	51.80	51.62	51.00	52.62
Sockeye Time	49.38	49.50	50.68	48.91
Surf	60.92	60.60	63.73	58.65

Stick week 02	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	51.14	50.41	52.90	51.21
Covington	52.30	54.29	57.03	53.82
Dark Grace Time	51.58	50.46	53.12	51.61
Dark Swing Time	53.13	54.35	56.55	56.44
Energy Time	62.30	61.52	62.62	63.04
Irvine	54.33	55.36	55.37	54.96
Sockeye Time	45.03	46.34	47.11	46.70
Surf	56.12	55.44	57.85	55.83

Average Spad reading on lower leaves.

Stick week 40	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	35.80	37.77	35.97	37.82
Covington	36.48	39.22	37.58	37.94
Dark Grace Time	46.78	44.79	43.65	43.24
Dark Swing Time	39.63	42.27	38.39	39.17
Energy Time	48.67	50.44	50.88	49.45
Irvine	36.34	38.30	35.53	36.43
Sockeye Time	39.79	40.40	38.72	39.48
Surf	35.73	39.11	35.11	41.61

Stick week 45	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	41.24	40.02	41.38	41.66
Covington	39.88	39.55	37.84	37.64
Dark Grace Time	47.15	46.63	47.24	47.26
Dark Swing Time	45.27	45.88	43.21	45.84
Energy Time	45.87	48.52	50.03	47.92
Irvine	43.08	41.30	42.27	41.20
Sockeye Time	41.83	43.00	45.51	43.85
Surf	42.71	41.46	44.95	39.85

Stick week 50	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	37.07	37.58	38.65	39.03
Covington	39.66	39.43	40.09	39.59
Dark Grace Time	44.44	46.28	45.13	44.65
Dark Swing Time	42.21	43.15	47.01	42.00
Energy Time	47.82	47.76	50.71	48.90
Irvine	39.63	39.50	41.62	40.39
Sockeye Time	39.98	40.25	42.47	40.74
Surf	41.53	42.28	44.04	42.32

Stick week 02	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	41.00	40.94	44.21	40.32
Covington	40.95	40.53	42.78	39.18
Dark Grace Time	45.78	45.48	45.55	46.42
Dark Swing Time	46.11	45.21	47.20	46.66
Energy Time	51.99	50.87	51.71	52.48
Irvine	42.75	42.56	43.50	42.73
Sockeye Time	40.68	40.17	41.14	41.05
Surf	44.45	44.24	44.24	42.68

Fresh weight (g) of 5 plants per pot

Stick week 40	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	164.2	158.8	180.6	168.3
Covington	162.3	148.0	174.3	156.4
Dark Grace Time	154.3	155.6	171.4	162.5
Dark Swing Time	175.4	169.5	181.5	177.1
Energy Time	169.5	156.1	154.8	170.8
Irvine	160.8	153.1	164.2	159.9
Sockeye Time	143.1	140.5	158.0	151.0
Surf	177.5	158.3	176.7	170.9

Stick week 45	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	147.4	145.9	151.7	151.5
Covington	145.3	139.3	151.3	147.0
Dark Grace Time	131.6	129.2	133.0	127.2
Dark Swing Time	175.3	168.7	186.4	175.5
Energy Time	154.3	151.2	156.7	152.0
Irvine	139.0	143.1	142.2	149.4
Sockeye Time	125.2	131.3	132.3	129.8
Surf	183.1	171.0	171.0	180.1

Stick week 50	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	193.7	187.3	184.7	182.9
Covington	179.2	173.6	172.3	178.1
Dark Grace Time	170.8	164.9	173.4	183.2
Dark Swing Time	206.6	201.1	200.5	218.8
Energy Time	183.5	175.2	181.9	197.1
Irvine	191.1	182.2	178.6	187.5
Sockeye Time	171.4	156.3	161.5	169.6
Surf	202.1	192.6	186.1	211.7

Stick week 02	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	210.5	198.7	211.2	219.1
Covington	184.0	186.1	195.3	198.8
Dark Grace Time	172.1	171.3	186.5	186.6
Dark Swing Time	227.0	227.3	233.6	224.9
Energy Time	170.6	168.0	184.0	188.6
Irvine	180.6	177.3	178.0	194.6
Sockeye Time	172.2	189.6	184.0	176.7
Surf	194.3	196.5	187.2	203.8

Dry weight (g) of 5 plants per pot (g)

Stick week 40	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	15.08	16.45	14.54	15.64
Covington	15.32	16.73	14.57	15.51
Dark Grace Time	15.24	17.31	15.06	16.20
Dark Swing Time	16.31	16.82	15.94	16.86
Energy Time	15.72	16.93	15.42	17.78
Irvine	16.37	17.96	15.61	17.65
Sockeye Time	14.04	15.50	13.41	14.92
Surf	16.86	17.27	15.06	16.77

Stick week 45	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	14.23	12.57	14.52	13.92
Covington	14.18	13.17	15.29	14.69
Dark Grace Time	13.38	12.50	13.35	13.01
Dark Swing Time	16.47	14.99	17.59	16.78
Energy Time	16.34	14.90	15.92	15.32
Irvine	14.54	13.59	14.83	15.63
Sockeye Time	12.52	12.42	13.79	13.13
Surf	16.93	15.41	16.44	17.38

Stick week 50	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	18.55	17.96	18.31	17.79
Covington	17.29	16.75	17.03	17.00
Dark Grace Time	17.65	16.87	18.17	18.90
Dark Swing Time	19.39	19.06	19.69	21.40
Energy Time	19.10	18.44	19.81	20.76
Irvine	19.57	18.66	18.91	20.04
Sockeye Time	16.82	15.33	16.28	16.99
Surf	18.42	17.57	17.86	20.50

Stick week 02	Ltd CO_2 -RH control	Ltd CO_2 +RH control	Std CO_2 -RH control	Std CO_2 +RH control
Chesapeake	20.66	18.95	21.01	21.99
Covington	19.22	18.84	20.44	20.78
Dark Grace Time	18.03	18.05	20.50	20.52
Dark Swing Time	22.91	22.49	24.34	23.37
Energy Time	19.46	18.59	21.43	22.02
Irvine	18.77	18.17	19.75	21.23
Sockeye Time	18.61	19.68	20.31	19.70
Surf	19.89	19.67	19.83	21.52

Summary of compost analyses taken at marketing stage 3.

pH

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	6.0	6.0	6.1	6.1
40	Sockeye Time	6.1	6.1	6.1	6.1
45	Dark Grace Time	6.0	6.2	6.1	6.1
45	Sockeye Time	6.1	6.2	6.3	6.3
50	Dark Grace Time	6.1	6.2	6.1	6.2
50	Sockeye Time	6.1	6.1	6.1	6.2
02	Dark Grace Time	5.9	5.8	5.9	6.0
02	Sockeye Time	6.0	5.9	5.9	6.0

Conductivity (µS/cm)

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	484.4	463.4	428.9	346.4
40	Sockeye Time	365.8	336.0	364.0	366.0
45	Dark Grace Time	398.8	473.5	433.2	386.7
45	Sockeye Time	344.4	360.3	303.3	323.1
50	Dark Grace Time	688.1	550.5	561.9	574.8
50	Sockeye Time	664.4	558.6	502.6	430.6
02	Dark Grace Time	468.7	599.7	428.9	456.0
02	Sockeye Time	402.6	657.1	633.4	401.7

Nitrate-N (mg/l)

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	111.9	116.1	79.9	53.2
40	Sockeye Time	43.7	54.8	26.6	61.5
45	Dark Grace Time	66.6	95.0	75.2	63.5
45	Sockeye Time	68.8	29.8	26.3	16.2
50	Dark Grace Time	110.3	66.4	98.6	38.7
50	Sockeye Time	105.8	69.6	35.0	39.9
02	Dark Grace Time	23.9	110.9	60.0	40.8
02	Sockeye Time	46.9	130.6	129.4	39.5

Ammonium-N (mg/l)

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	11.8	15.0	4.2	5.2
40	Sockeye Time	2.8	4.0	2.7	3.0
45	Dark Grace Time	1.2	0.8	0.6	1.1
45	Sockeye Time	1.5	1.3	0.7	0.5
50	Dark Grace Time	3.1	2.1	1.6	0.8
50	Sockeye Time	1.5	2.3	1.0	0.8
02	Dark Grace Time	1.0	1.0	0.9	1.5
02	Sockeye Time	2.0	2.0	2.2	2.3

Potassium (mg/l)

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	116.5	123.5	92.4	66.7
40	Sockeye Time	106.4	90.6	78.1	65.3
45	Dark Grace Time	112.1	140.4	133.3	60.2
45	Sockeye Time	95.7	97.4	113.6	43.4
50	Dark Grace Time	122.0	73.5	96.9	80.7
50	Sockeye Time	127.4	94.0	75.9	95.3
02	Dark Grace Time	78.1	112.4	78.5	75.3
02	Sockeye Time	74.3	117.0	108.5	63.9

Calcium (mg/l)

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	120.4	137.8	125.5	101.8
40	Sockeye Time	107.3	99.5	117.0	100.6
45	Dark Grace Time	102.4	105.0	103.0	89.8
45	Sockeye Time	87.0	90.4	69.8	73.1
50	Dark Grace Time	167.0	107.0	137.1	120.9
50	Sockeye Time	167.7	146.6	111.7	111.1
02	Dark Grace Time	105.8	149.3	97.6	99.6
02	Sockeye Time	90.8	156.1	140.5	82.8

Magnesium (mg/l)

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	84.5	99.7	94.0	63.2
40	Sockeye Time	72.4	69.0	81.2	68.0
45	Dark Grace Time	69.3	72.1	76.0	56.2
45	Sockeye Time	53.4	62.1	47.1	49.9
50	Dark Grace Time	140.0	90.1	123.8	108.6
50	Sockeye Time	139.7	126.7	100.0	98.0
02	Dark Grace Time	89.4	128.1	81.2	87.3
02	Sockeye Time	75.2	130.6	120.8	72.3

Phosphorus (mg/l)

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	27.3	30.0	28.2	24.8
40	Sockeye Time	26.1	26.5	25.5	23.2
45	Dark Grace Time	21.3	20.6	20.3	22.8
45	Sockeye Time	22.1	22.4	20.7	20.3
50	Dark Grace Time	24.1	17.8	19.9	19.9
50	Sockeye Time	28.4	20.0	20.0	26.7
02	Dark Grace Time	25.4	26.5	24.1	24.1
02	Sockeye Time	26.4	25.3	20.9	26.2

Iron (mg/l)

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	0.9	1.1	1.0	1.6
40	Sockeye Time	1.5	1.3	1.1	1.0
45	Dark Grace Time	0.7	1.1	1.4	0.7
45	Sockeye Time	0.8	0.9	1.4	1.1
50	Dark Grace Time	1.8	0.9	1.0	1.1
50	Sockeye Time	1.2	1.1	0.8	1.4
02	Dark Grace Time	1.6	0.9	1.1	1.3
02	Sockeye Time	1.0	0.8	0.9	1.0

Zinc (mg/l)

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	0.2	0.2	0.2	0.2
40	Sockeye Time	0.2	0.2	0.2	0.2
45	Dark Grace Time	0.3	0.2	0.2	0.2
45	Sockeye Time	0.3	0.3	1.2	0.2
50	Dark Grace Time	0.1	0.1	0.2	0.1
50	Sockeye Time	0.1	0.1	0.1	0.2
02	Dark Grace Time	0.1	0.1	0.1	0.1
02	Sockeye Time	0.2	0.2	0.2	0.1

Manganese (mg/l)

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	0.0	0.0	0.0	0.0
40	Sockeye Time	0.0	0.0	0.0	0.0
45	Dark Grace Time	0.0	0.1	0.1	0.0
45	Sockeye Time	0.1	0.1	0.0	0.0
50	Dark Grace Time	0.1	0.1	0.1	0.1
50	Sockeye Time	0.1	0.1	0.1	0.0
02	Dark Grace Time	0.0	0.0	0.0	0.0
02	Sockeye Time	0.0	0.0	0.0	0.0

Copper (mg/l)

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	0.1	0.1	0.1	0.1
40	Sockeye Time	0.1	0.1	0.1	0.1
45	Dark Grace Time	0.3	0.3	0.2	0.2
45	Sockeye Time	0.3	0.2	0.2	0.2
50	Dark Grace Time	0.1	0.1	0.1	0.1
50	Sockeye Time	0.1	0.1	0.1	0.2
02	Dark Grace Time	0.1	0.1	0.1	0.1
02	Sockeye Time	0.1	0.2	0.1	0.2

nd = below limits of detection

Boron (mg/l)

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	nd	nd	nd	nd
40	Sockeye Time	nd	nd	nd	nd
45	Dark Grace Time	0.1	0.1	nd	nd
45	Sockeye Time	0.1	0.0	nd	nd
50	Dark Grace Time	0.1	0.1	0.0	0.0
50	Sockeye Time	0.1	0.1	0.0	0.1
02	Dark Grace Time	0.1	0.0	0.1	0.0
02	Sockeye Time	0.1	0.0	0.1	0.1

Sodium (mg/l)

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	340.9	366.8	349.3	275.5
40	Sockeye Time	276.5	267.7	302.1	287.3
45	Dark Grace Time	211.4	235.6	239.0	198.9
45	Sockeye Time	188.4	177.0	180.2	162.6
50	Dark Grace Time	437.0	402.7	381.8	409.1
50	Sockeye Time	428.1	378.6	331.6	372.6
02	Dark Grace Time	414.3	452.0	338.9	372.9
02	Sockeye Time	356.8	513.7	492.7	350.6

Chloride (mg/l)

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	319.2	302.9	281.0	231.4
40	Sockeye Time	253.8	212.8	227.7	259.1
45	Dark Grace Time	270.0	274.4	264.6	250.0
45	Sockeye Time	206.8	195.1	180.8	191.6
50	Dark Grace Time	406.9	381.7	379.3	379.4
50	Sockeye Time	368.9	377.4	350.4	325.9
02	Dark Grace Time	334.1	381.3	266.6	317.1
02	Sockeye Time	226.3	441.1	396.0	254.0

Sulphate-S (mg/l)

Stick week	Variety	Ltd CO_2 +RH Control	Ltd CO_2 -RH control	Std CO_2 +RH Control	Std CO_2 -RH Control
40	Dark Grace Time	198.9	213.8	220.0	173.6
40	Sockeye Time	198.2	175.1	231.8	172.4
45	Dark Grace Time	155.5	170.1	190.0	159.1
45	Sockeye Time	128.6	192.6	172.8	167.0
50	Dark Grace Time	246.4	194.6	205.5	236.8
50	Sockeye Time	257.4	242.6	230.3	239.5
02	Dark Grace Time	254.9	257.8	185.9	235.9
02	Sockeye Time	207.4	247.5	228.4	199.8

Summary of leaf tissue analyses taken at marketing stage 3.

%N

Stick week	Variety	Ltd CO_2 +RH control	Ltd CO_2 -RH control	Std CO_2 +RH control	Std CO_2 -RH control
40	Dark Grace Time	4.52	4.46	4.14	4.04
40	Sockeye Time	4.54	4.47	4.10	4.31
45	Dark Grace Time	4.96	4.84	4.70	4.48
45	Sockeye Time	4.72	4.83	4.41	4.42
50	Dark Grace Time	4.59	4.82	4.65	4.47
50	Sockeye Time	4.87	5.00	4.61	4.72
02	Dark Grace Time	4.33	4.53	4.25	4.70
02	Sockeye Time	4.29	4.54	4.30	4.46

%C

Stick week	Variety	Ltd CO_2 +RH control	Ltd CO_2 -RH control	Std CO_2 +RH control	Std CO_2 -RH control
40	Dark Grace Time	40.73	39.75	39.91	38.97
40	Sockeye Time	38.97	39.19	40.09	38.97
45	Dark Grace Time	41.22	42.28	42.38	42.17
45	Sockeye Time	41.17	41.64	42.45	41.68
50	Dark Grace Time	41.71	42.03	41.89	42.17
50	Sockeye Time	40.39	40.88	41.11	41.18
02	Dark Grace Time	41.31	40.55	41.59	42.09
02	Sockeye Time	40.55	41.14	41.56	41.66

%Ca

Stick week	Variety	Ltd CO_2 +RH control	Ltd CO_2 -RH control	Std CO_2 +RH control	Std CO_2 -RH control
40	Dark Grace Time	1.02	0.91	0.91	0.95
40	Sockeye Time	1.02	0.98	0.88	1.03
45	Dark Grace Time	0.91	0.92	0.84	0.85
45	Sockeye Time	0.86	0.97	0.81	0.93
50	Dark Grace Time	0.80	0.83	0.93	0.73
50	Sockeye Time	0.83	0.91	0.90	0.83
02	Dark Grace Time	0.83	0.73	0.80	0.69
02	Sockeye Time	0.85	0.88	0.89	0.79

%K

Stick week	Variety	Ltd CO_2 +RH control	Ltd CO_2 -RH control	Std CO_2 +RH control	Std CO_2 -RH control
40	Dark Grace Time	4.69	4.56	4.45	4.41
40	Sockeye Time	5.07	4.86	4.85	4.73
45	Dark Grace Time	4.72	4.45	4.34	4.40
45	Sockeye Time	4.74	4.37	4.18	4.24
50	Dark Grace Time	3.87	4.05	4.11	3.75
50	Sockeye Time	4.27	4.20	4.36	4.05
02	Dark Grace Time	4.33	4.81	4.43	3.82
02	Sockeye Time	4.52	4.55	4.44	4.06

% Mg

Stick week	Variety	Ltd CO_2 +RH control	Ltd CO_2 -RH control	Std CO_2 +RH control	Std CO_2 -RH control
40	Dark Grace Time	0.36	0.35	0.33	0.34
40	Sockeye Time	0.40	0.39	0.36	0.40
45	Dark Grace Time	0.31	0.31	0.30	0.31
45	Sockeye Time	0.33	0.37	0.32	0.35
50	Dark Grace Time	0.27	0.29	0.29	0.25
50	Sockeye Time	0.30	0.35	0.32	0.30
02	Dark Grace Time	0.29	0.25	0.27	0.25
02	Sockeye Time	0.30	0.33	0.31	0.29

%Na

Stick week	Variety	Ltd CO_2 +RH control	Ltd CO_2 -RH control	Std CO_2 +RH control	Std CO_2 -RH control
40	Dark Grace Time	0.35	0.33	0.33	0.38
40	Sockeye Time	0.33	0.34	0.32	0.35
45	Dark Grace Time	0.34	0.31	0.29	0.33
45	Sockeye Time	0.33	0.28	0.28	0.28
50	Dark Grace Time	0.33	0.33	0.39	0.34
50	Sockeye Time	0.35	0.34	0.31	0.30
02	Dark Grace Time	0.35	0.45	0.39	0.36
02	Sockeye Time	0.39	0.36	0.34	0.28

%S

Stick week	Variety	Ltd CO_2 +RH control	Ltd CO_2 -RH control	Std CO_2 +RH control	Std CO_2 -RH control
40	Dark Grace Time	0.23	0.21	0.20	0.18
40	Sockeye Time	0.23	0.22	0.21	0.21
45	Dark Grace Time	0.20	0.18	0.18	0.17
45	Sockeye Time	0.19	0.19	0.18	0.17
50	Dark Grace Time	0.17	0.17	0.18	0.15
50	Sockeye Time	0.17	0.18	0.16	0.18
02	Dark Grace Time	0.20	0.17	0.17	0.15
02	Sockeye Time	0.18	0.18	0.17	0.15

%P

Stick week	Variety	Ltd CO_2 +RH control	Ltd CO_2 -RH control	Std CO_2 +RH control	Std CO_2 -RH control
40	Dark Grace Time	0.88	0.82	0.81	0.79
40	Sockeye Time	0.93	0.87	0.84	0.88
45	Dark Grace Time	1.01	0.94	0.88	0.88
45	Sockeye Time	0.95	0.97	0.82	0.86
50	Dark Grace Time	0.83	0.93	0.87	0.77
50	Sockeye Time	1.02	0.96	0.85	0.94
02	Dark Grace Time	0.88	0.76	0.72	0.71
02	Sockeye Time	0.79	0.75	0.72	0.72

B (ppm)

Stick week	Variety	Ltd CO_2 +RH control	Ltd CO_2 -RH control	Std CO_2 +RH control	Std CO_2 -RH control
40	Dark Grace Time	27.56	22.03	24.16	22.73
40	Sockeye Time	27.22	24.82	24.86	26.64
45	Dark Grace Time	26.03	26.61	25.78	22.20
45	Sockeye Time	24.00	26.70	24.14	25.88
50	Dark Grace Time	21.01	22.90	23.17	20.41
50	Sockeye Time	22.89	24.96	22.88	24.44
02	Dark Grace Time	27.68	24.86	25.15	19.72
02	Sockeye Time	23.71	26.12	27.45	21.05

Cu (ppm)

Stick week	Variety	Ltd CO_2 +RH control	Ltd CO_2 -RH control	Std CO_2 +RH control	Std CO_2 -RH control
40	Dark Grace Time	20.21	18.45	18.00	20.80
40	Sockeye Time	22.08	18.73	22.01	23.11
45	Dark Grace Time	23.64	17.45	17.39	22.09
45	Sockeye Time	22.41	18.09	17.38	21.87
50	Dark Grace Time	19.15	18.63	23.09	22.30
50	Sockeye Time	19.94	17.97	23.82	24.02
02	Dark Grace Time	18.29	15.41	15.13	12.47
02	Sockeye Time	17.32	15.27	16.24	13.01

Fe (ppm)

Stick week	Variety	Ltd CO_2 +RH control	Ltd CO_2 -RH control	Std CO_2 +RH control	Std CO_2 -RH control
40	Dark Grace Time	92.48	118.38	100.48	94.60
40	Sockeye Time	120.15	107.85	84.81	110.49
45	Dark Grace Time	54.94	68.13	62.57	53.56
45	Sockeye Time	56.46	61.83	60.42	63.67
50	Dark Grace Time	47.18	48.90	49.35	41.62
50	Sockeye Time	48.26	53.78	55.93	49.08
02	Dark Grace Time	52.54	43.80	46.78	42.53
02	Sockeye Time	45.70	60.87	72.64	56.42

Mn (ppm)

Stick week	Variety	Ltd CO_2 +RH control	Ltd CO_2 -RH control	Std CO_2 +RH control	Std CO_2 -RH control
40	Dark Grace Time	164.36	138.33	133.26	143.97
40	Sockeye Time	143.94	148.37	121.31	155.09
45	Dark Grace Time	139.38	138.69	130.10	110.44
45	Sockeye Time	116.01	153.72	119.45	142.11
50	Dark Grace Time	127.22	142.04	132.15	113.90
50	Sockeye Time	137.94	159.19	125.44	142.55
02	Dark Grace Time	156.93	127.37	123.23	119.83
02	Sockeye Time	110.47	121.64	119.75	116.58

Zn (ppm)

Stick week	Variety	Ltd CO_2 +RH control	Ltd CO_2 -RH control	Std CO_2 +RH control	Std CO_2 -RH control
40	Dark Grace Time	50.49	43.05	53.03	49.77
40	Sockeye Time	57.81	50.91	60.91	48.88
45	Dark Grace Time	59.98	52.05	62.55	51.39
45	Sockeye Time	57.01	50.65	57.37	48.94
50	Dark Grace Time	49.61	57.82	55.80	47.14
50	Sockeye Time	52.73	53.03	53.06	50.92
02	Dark Grace Time	48.56	50.45	49.32	34.76
02	Sockeye Time	46.59	40.17	50.14	38.64

Appendix 6 – Photographs illustrating pot deterioration score 3
Illustration of pot deterioration stage 3

Chesapeake

Covington

Dark Grace Time

Dark Swing Time

Energy Time

Irvine

Sockeye Time

Surf