Project title:	Assessing the benefits of deleafing in peppers
Project number:	PC 285a
Project leader:	Tim Pratt, FEC Services Ltd
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Key staff:	Tim Pratt Veronica Valdes Jon Swain
Location of project:	Valley Grown Nurseries, Warwick HRI FEC Services Ltd
Industry Representative:	Gary Taylor, Valley Grown Nurseries
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Key words:	deleafing, energy, water, irrigation, labour, sweet peppers

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

- Deleafing sweet pepper crops saves energy and has no detrimental effect on plant growth, health, pests and yields
- Labour costs can be high and growers considering deleafing should carry out a financial appraisal before making the final decision.

Background and expected deliverables

Sweet pepper plants grow 70-100 mm per week throughout the growing season resulting in a very large total leaf area which can be eight times the floor area of the glasshouse by the end of the season. As the year progresses, the lower leaves become largely redundant in terms of production of assimilates but continue to transpire and to have an impact on the environment within the crop canopy.

Removing lower leaves may have no detrimental impact on yield and may save water and energy, as water efficiency would improve resulting in less heat being required to drive transpiration.

There could also be a lower risk of disease because of lower relative humidity and the fact that the lower stems would be cleaner and drier, although wound sites from deleafing could increase stem fungal disease. In addition deleafing might change the microclimate around flowers and developing fruit affecting the incidence of fruit rot.

Deleafing might also influence the populations of pests and beneficial species which might otherwise inhabit the lower leaves.

Project PC 285 “Assessing the benefits of deleafing in peppers” was extended for an additional year. Work carried out in 2009 showed that deleafing saved around 8% of weekly energy use towards the end of the season (approximately 5 kWh/m^2 of gas annually) without any loss of yield or fruit quality or an increase in disease incidence.

However in 2009 there were problems with the reliability of drain measuring equipment because it kept blocking with debris and there was a sparsity of plant measurements. Results were therefore not necessarily representative so the project was extended for another year to more accurately assess water consumption.

The extension was an opportunity to validate previous results on humidity, energy saving and financial benefits. An assessment of the effect of deleafing on pests and biocontrols was also made.

Summary of project and main conclusions

In 2010 the same commercial crop of cultivar Cupra was used at the same site, Valley Grown Nurseries (VGN). The crops were grown in the same blocks 4, 5, and 6. However, the blocks used previously as the control and deleafing block were switched to make comparisons more robust. Table 1 lists the block treatments and Figure 1 depicts the control and treatment blocks.

Table 1. Block treatments in 2009 and 2010

Block	**2009 treatment**	**2010 treatment**
Block 4	Control	Deleafed
Block 5	Control	Deleafed
Block 6	Deleafed	Control

Since it was proven in 2009 that deleafing causes no decrease in yield, leaves were removed up to the V in all three blocks in week 22 in 2010. No more leaves were removed in the control block 6, whilst additional deleafing was carried out in blocks 4 and 5 starting from week 30 as given in Table 2 below:

Table 2. The timing of deleafing and the approximate height of leaves removed per stem

Week number	**Amount of leaf removed per stem (cm)**
22	50 (in all blocks)
30	60 (in blocks 4 and 5)
33	40 (in blocks 4 and 5)
37	30 (in blocks 4 and 5)

Figure 1. Control to the left and deleafing to the right

The environmental control of the 3 blocks was carried out in the same way with the same configuration of measuring boxes as in 2009 with the addition of independent sensors in all 3 measuring boxes in both block 5 (deleafed) and in block 6 (control).

A Martin Drop Drain Water Logger (DWL) was installed and used to measure water take up of whole rows in addition to the Priva tipping spoon method used in 2009.

The yield (class 1, class 2 and waste) and other crop data were recorded and analysed by block and the plants were monitored at regular intervals for disease and for pest and beneficial species activity.

Environmental conditions

- Deleafing made no difference in temperatures in the blocks over and above the inherent block differences
- Deleafing caused no difference to CO_2 levels
- Deleafing improved humidity conditions (lower RH and higher HD)

External air temperature and solar radiation in 2009 and 2010 were very similar making data comparable across the two years.

In all previous years, block 6 (then subject to deleafing) recorded lower temperatures than block 5. In 2010 temperatures were once again lower in block 6 (now the control) than in block 5 (deleafed), both at the left and right hand side of the path, and at the top and bottom of the canopy. It therefore appears that the temperature differences between the blocks 6 and 5 were due to inherent differences between the blocks rather than to the effect of deleafing.

Findings for CO_2 were similar, with block 5 showing higher daytime concentrations than block 6 no matter which block housed the deleafed plants.

In terms of humidity, the data from the independent humidity sensors showed a very similar RH at the top of the canopy on the right hand side in both blocks with no clear difference in RH after the deleafing treatment started.

However there was a reduction in the RH at the bottom of the canopy in the deleafed block 5 which does appear to be related to the deleafing treatment. Prior to deleafing the RH in both blocks at the bottom of the plant were very similar. After deleafing started the RH at the bottom in block 5 (deleafed) was on average 3% lower – see Figures 2 and 3 below:

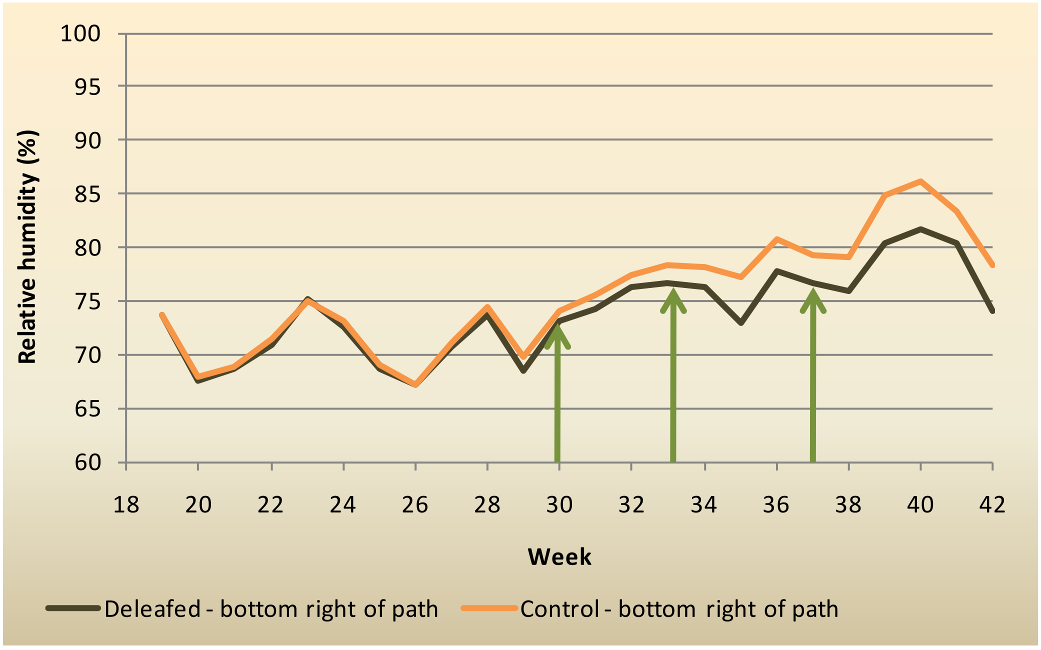

Figure 2. The average weekly relative humidity at the bottom of the plant to the right hand side of the path

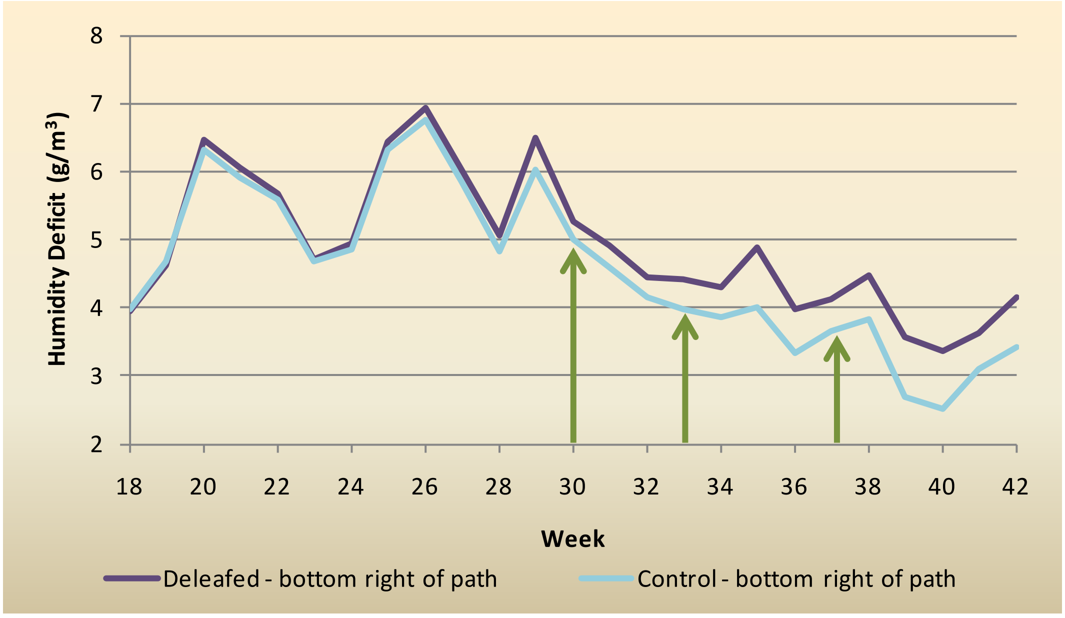

Figure 3. The average weekly humidity deficit at the bottom of the plant to the right hand side of the path

Energy use

The 2010 results support those of 2009 and show that deleafing can deliver savings in energy use

- Energy savings of 1.1% were measured during deleafing periods resulting in a 0.25% saving over the whole season
- More stringent humidity control has the potential to save further energy

The energy used in blocks 5 (deleafed) and 6 (control) was very similar up to the beginning of week 23.

- From that point on up to the start of deleafing in week 30 the control block used an average of 3.8% more energy
- From the start of deleafing to week 42, the control block used an average of 4.9% more energy - an increase in savings of 1.1%

Energy saving figures are given in Figure 4 and Table 3.

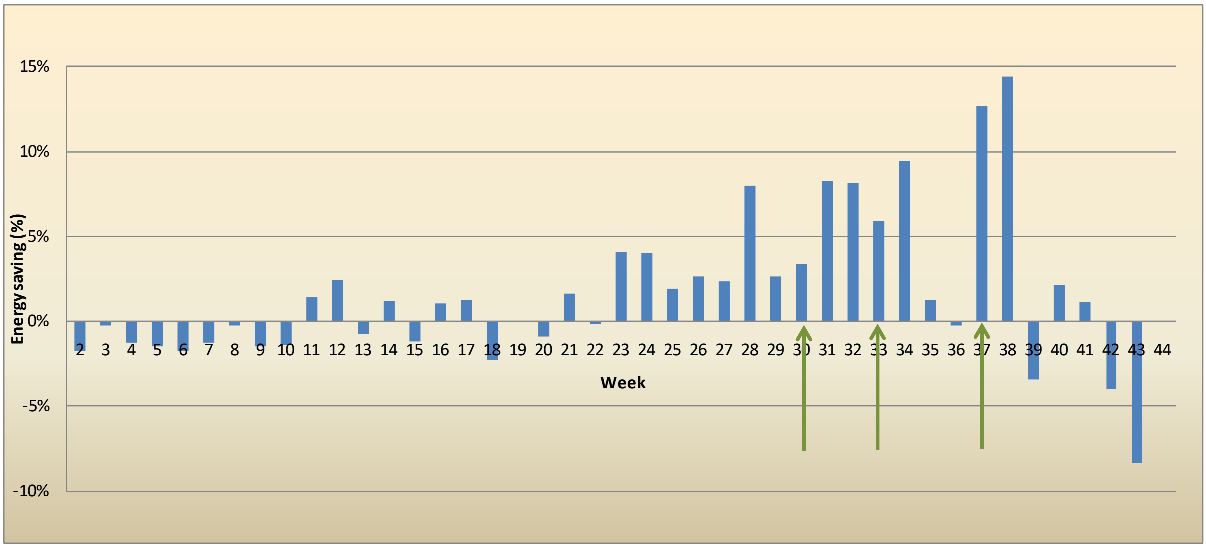

Figure 4. Percentage energy saving (positive values) in the deleafed block by week

Table 3. The effect on energy consumptions during relevant periods

	Deleafed kWh/m²	**Control kWh/m²**	**Difference kWh/m²**	**% saving**
Energy consumption - sum from week 1 to end week 22	202.27	201.20	-1.1	-0.53%
Energy consumption - sum from week 23 to end week 29	31.75	33.01	1.3	3.81%
Difference 1st deleafing (week 30 - 32)	*13.97*	*14.95*	*1.0*	*6.60%*
Difference 2nd deleafing (week 33 - 36)	*18.48*	*19.31*	*0.8*	*4.31%*
Difference 3rd deleafing (week 37 - week 42)	*32.97*	*34.54*	*1.6*	*4.52%*
Energy consumption - sum after deleafing started (from week 30 to week 42)	65.42	68.80	3.4	4.91%
Energy consumption as whole season total	299.4	303.0	3.6	1.18%

Whilst a 0.25% energy saving is not significant for most nurseries, further energy savings can be realised by better humidity control. Indications from this experiment have shown that an annual saving of 3.4% is possible (12kWh/m^2/year of gas).

Water use

- Data from on site measurements shows little effect of deleafing on water use
- Longer term water data shows reduction in water use in deleafed areas, although this is attributed to increased monitoring of water use and action taken to reduce high levels of drain

The primary and best method of recording the change in water use by plants in each block proved to be the Martin Drop Drain Water Logger (DWL) i.e. the whole row system.

However, while the uptake in block 5 (deleafed) might have been expected to fall as the leaf area was removed, this was not supported by the data. Block 6 (control) showed a greater uptake than block 5 (deleafed) during the whole season but once deleafing started, the difference between the blocks actually reduced, instead of increasing. No firm conclusions can be drawn from this as it contradicts all accepted thinking regarding the influence of deleafing on uptake.

Long term water consumption data provided by the nursery shows a 11% reduction in water use for years when deleafing was carried out. This is unsubstantiated as a direct result of deleafing but it shows the benefit of close monitoring of water use and the reductions than can ensue.

Crop growth and yield

- Plant height was unaffected by deleafing
- Total flowers, fruit sets and fruit cuts per plant were also unaffected
- There was a small improvement in yield of Class 1 fruit but this was less than 5% and so statistically insignificant
- There were more Class 2 fruit in the control block but this is thought to be unrelated to deleafing

There was very little evidence for any significant effect of deleafing on weekly growth as recorded by VGN staff and this is supported by crop heights measured by FEC/Warwick HRI. There was no significant impact on the total number of flowers, fruit set and fruits cut per plant over the course of the growing season or indeed in any given week after the treatment started. Although there were some small differences in yields between the control and deleafed blocks, these were also statistically insignificant.

Disease monitoring

- Deleafing had no effect on the number or location of stem lesions
- Deleafing had no effect on the incidence of internal fruit rot caused by *Fusarium* sp.
- There was a similar quantity of fruit wastage due to disease in both the control and deleafed blocks

Overall, the results relating to disease confirm those found in 2009 and indicate that deleafing neither increases nor reduces the incidence of Botrytis stem rot or Fusarium internal fruit rot.

The crop was examined for disease on three occasions:

1. 27 May (in week 21 before the start of deleafing)
2. 18 August (in week 33 during deleafing)
3. 13 October 2010 (in week 41 after the completion of deleafing)

No stem lesions were found at the crop inspection in May and only a few in August. In October, the incidence of stems with spreading lesions combined with the number of missing stems accounted for 1-2% of total stem numbers. *Botrytis cinerea* was recovered from three out of four spreading lesions tested and Fusarium sp. from the other.

In August around 100 visibly healthy fruit from each of the leafed and deleafed areas of crop were examined for internal infection by Fusarium sp. There was no significant difference between blocks in the proportion of fruit affected by Fusarium, which ranged from 40% to 45%, mostly affecting the seed only.

The levels of fruit wastage by weight based on nursery picking records for the three blocks showed that wastage was largely due to Fusarium fruit rot. As in 2009, wastage in block 4 was greater than in blocks 5 and 6, even though blocks used for control and deleafing had changed. This strongly indicates that block 4 has a different environment to the other blocks (supported by grower observations), more favourable to development of Fusarium fruit rot, than blocks 5 and 6.

Pest monitoring

- Deleafing had no significant effect on pest or beneficial species activity
- There were more spot sprays to block 6 (control) which implied deleafing was beneficial but results overall were inconclusive

Numbers of pest and beneficial species were estimated on four occasions and the results from the control and deleafed blocks compared:

1. 8 July (in week 27)
2. 29 July (in week 30)
3. 31 August (in week 35)
4. 12 October 2010 (in week 41)

At the start of the experiment pest populations were quite small and similar throughout the three blocks, the most important beneficial insects could be found everywhere, and pest activity remained low throughout the year. This was largely due to well managed IPM during the first half of the season.

There was very little invertebrate activity in the lower canopy from July onwards, showing that the lower leaves did not house a reservoir of pest or beneficial species.

More spot sprays were applied against *Aulocorthum solani* in the control block than in the other two blocks. Although this implied that there was a benefit from deleafing, the effect was not supported by the counts in the main assessments.

Overall, the formal pest monitoring did not reveal any evidence to suggest that the removal of lower leaves had any detrimental effect on IPM.

Financial benefits

To ascertain the true benefit to the nursery from deleafing all the factors need to be considered in financial terms e.g. reduced spray applications, increased labour etc.

Table 4 is a financial appraisal of deleafing in 2010.

Table 4. Overall economic appraisal for 2010 season

Type	Description	Saving £/m^2
Energy	0.88 kWh/m^2 gas	£0.03
Crop protection	Reduced application of sprays	£0.10
Labour	End of year turnaround	£0.05
Waste removal	1 fewer skip	£0.10
Labour	Removal of leaves	-£0.30
Balance		**-£0.02**

Deleafing will cost the nursery £200 per hectare based on the results of the 2010 season however if savings from better humidity control and water savings are made (as reported by the site water meter) then the following table shows the value of deleafing to the nursery.

Table 5. Overall economic appraisal with increased energy and water savings

Type	Description	Saving £/m^2
Energy	12 kWh/m^2 gas	£0.36
Water	300litres/m^2	£0.52
Crop protection	Reduced application of sprays	£0.10
Labour	End of year turnaround	£0.05
Waste removal	1 fewer skip	£0.10
Labour	Removal of leaves	-£0.30
Balance		**£0.83**

If these savings are possible then the nursery will benefit by £0.83/m^2 or £8,300/Ha per annum.

Action points for growers

- Carry out regular maintenance and checking of measuring boxes to ensure best possible conditions whilst minimising energy consumption
- Install additional measuring boxes to allow humidity control at the bottom of the plant if deleafing for energy saving
- Anyone considering carrying out deleafing should carefully assess their individual circumstances and carry out a thorough financial appraisal before making a final decision.

- Minimise the number of deleafings to two (after deleafing to the V) to ensure lowest labour costs

SCIENCE SECTION

Introduction

This report continues work from PC 285 Assessing the benefits of deleafing in peppers.

Problems had been encountered in 2009 with the reliability of the drain measuring equipment and it had not been possible to quantify any savings in terms of water uptake. Furthermore, the drain was only measured from relatively few plants and so was not necessarily representative of the whole block.

Therefore the objectives for 2010 were to more accurately assess water consumption and potential energy savings. This included examining the drain and uptake from a whole row in each block, so data would be more representative.

Extending the project also served to validate previous results and gave the opportunity to assess the effect of deleafing in terms of pests and biocontrol (not included in the previous year).

In theory, there are three possible ways in which leaf removal from the lower canopy could influence Integrated Pest Management (IPM):

1. The lower leaves may provide harbourage for pests which remain a constant threat to the new foliage in the upper canopy. Therefore removing these leaves would be an advantage.
2. The lower leaves may retain a reservoir of beneficial species and therefore removing these leaves may be disadvantageous.
3. By altering the environment within the overall crop canopy, the older leaves may create conditions that are either more or less suitable for invertebrate species.

The impact on IPM will depend on which pest and beneficial species gain most benefit from these conditions.

Previous project reports:

- Annual report 2009 – report on the experiment carried out April – November 2008
- Final report 2010 – report on the experiment carried out April 2008 – November 2009

In 2010 the same commercial crop of cultivar Cupra was grown at Valley grown Nurseries (VGN) in blocks 4, 5, and 6. However, the blocks used for control and deleafing were switched to make comparisons more robust.

Table 6. Block treatments in 2009 and 2010

Block	2009 treatment	2010 treatment
Block 4	Control	Deleafed
Block 5	Control	Deleafed
Block 6	Deleafed	Control

Summary of the 2009 experiment

Method

In 2009 the plants in blocks 4 and 5 were left intact (without deleafing) as a control while the plants in block 6 were deleafed. The purpose of deleafing a whole block was to quantify the effects on humidity, energy use, water use and disease.

The goal was to leave 1.6 m of leaf on each shoot. The amount of leaf was allowed to increase to 2 m over the summer as transpiration can be desirable for cooling during this period and slightly more leaf may be needed when light levels are high.

Yield

The experiment proved that the leaf area in sweet peppers can be reduced without any significant effect on yield or fruit quality. The cumulative yields of class 1 fruits in the control and deleafed areas were 28.4 and 28.3 kg/m^2, while class 2 yields were 0.8 and 0.7 kg/m^2, respectively. There was very little evidence for any significant effect of deleafing on weekly growth or plant height. Furthermore, deleafing did not have a significant impact on the total number of flowers, fruit set and fruits cut per plant over the course of the growing season.

Water

It was not possible to quantify any saving in terms of water uptake in the 2009 experiment. The amount of irrigation applied (dose) was based on the duration of each irrigation round. A tipping spoon system was used to measure drainage for 10 plants in each block. The drain measurement equipment was unreliable because it kept blocking with debris. The uptake (primarily transpiration) was calculated as the irrigation applied minus the drain. While the uptake in block 6 might have been expected to be reduced due to the reduced leaf area, this was not supported by the data, probably because the plants on the drain equipment in block 5 (control) were smaller than those in block 6 (deleafed).

Environmental and CO_2

The independent temperature/humidity sensors showed that the deleafed block was less humid and sometimes slightly cooler. This was explained in part because of the expected reduced transpiration and the effect that this would have on the need for humidity control. However, comparison of the independent RH data with that from the climate control computer showed differences which were thought to be due to the accuracy of the temperature beads used for the wet and dry bulb measurements. As a result the deleafed block read a higher RH than was probably the case, which would have increased the venting and pipe temperature. This made it more complicated to assess the effect of deleafing and highlighted the need for accurate measurement.

The daytime CO_2 concentrations were greater in block 5 (control) when compared with block 6 (deleafed) especially early in the year before treatments were applied. Similar differences were found in previous years. Therefore, this effect was assumed due to block differences (block 5 being closer to the CO_2 inlet), rather than due to the effect of deleafing.

Energy

The reduction in transpiration as a result of deleafing should result in energy savings. In the 2009 experiment, deleafing in peppers showed a saving of around 8% of weekly energy use towards the end of the season (approximately 5 kWh/m^2 of gas annually). However, due to intrinsic differences between blocks and the subtle difference in humidity control, it was very difficult to be precise about the exact savings. Correction factors were used to take into account the block differences when heating, when at minimum pipe and for differences in humidity control. However, such corrections are imprecise and the block differences probably changed with external weather conditions.

Disease

Spreading stem lesions and plant death caused by *Botrytis cinerea* and Fusarium sp. occurred towards the end of the cropping season in both the deleafed and control blocks, and at a similar level in the two treatments. These results suggested that deleafing in pepper had little impact on occurrence of stem disease.

The effect on Fusarium internal fruit rot was also examined. Even though the humidity in the deleafed block was slightly lower, there was no real evidence to suggest that this affected the occurrence of internal fruit rot and hence wastage. There was a bigger difference between blocks than there was between treatments.

Materials and Methods

Experimental design at VGN

The experiment was carried out at Valley Grown Nurseries (VGN) on a commercial crop of cv. Cupra in 2010 grown in blocks 4, 5 and 6. The crop was grown on rockwool slabs. Three heads were trained from each plant, keeping the same shoot density as in previous years. Polythene sheets were used to separate block 4 from 5 and block 5 from 6.

Since results from 2009 showed that deleafing did not cause a decrease in yield, leaves were removed up to the V in all three blocks in week 22 in 2010. No more leaves were removed in the control block 6, while deleafing was carried out in blocks 4 and 5 starting from week 30.

The timing of deleafing and the approximate height of leaves removed per stem are shown in Table 7. In total, 180 cm of leaf was removed from the plants in blocks 4 and 5 and 50 cm from the plants in block 6. This compares to 2009 when the control plants were left intact and a total of 125 cm of leaf was removed from the deleafed plants.

Table 7. The timing of deleafing and the approximate height of leaves removed per stem

Week number	Amount of leaf removed per stem (cm)
22	50 (in all blocks)
30	60 (in blocks 4 and 5)
33	40 (in blocks 4 and 5)
37	30 (in blocks 4 and 5)

Figure 5. Control to the left and deleafing to the right

Environmental and energy recording

The environmental control of the three blocks was carried out the same way as in 2009 (Figure 6).

1. In block 4 (deleafed) via one measuring box located at the top of the canopy.
2. In blocks 5 (deleafed) and 6 (control) there were two measuring boxes at the top of the canopy in each block, one on each side of the path. The average of the two in each block was used for control.
3. In blocks 5 (deleafed) and 6 (control) there was a third measuring box installed, at the bottom of the canopy on the right hand side of the path.

All measured temperature and humidity, with the recordings going into the Priva climate control computer.

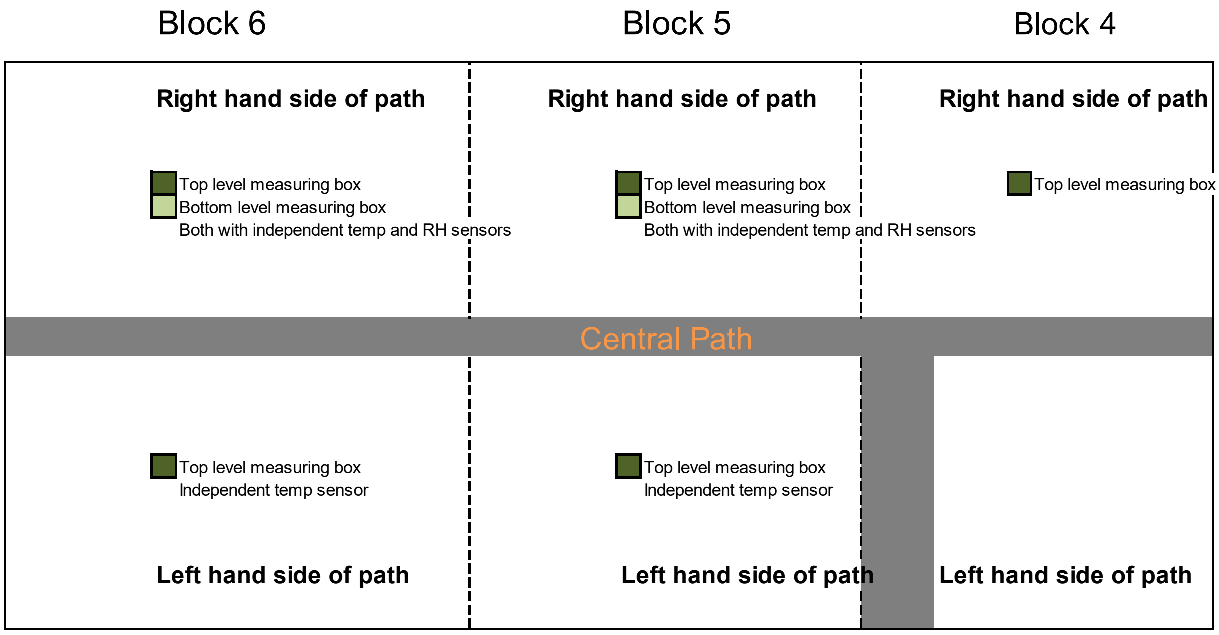

Figure 6. Site plan of the test compartments used throughout the experiment

For the 2010 season independent sensors were also installed in all three measuring boxes in block 5 (deleafed) and in 6 (control). Sensors on the right hand side of the path measured temperature and humidity while the sensors on the left hand side of the path measured temperature only.

Figure 7. Measuring box with independent temperature and humidity probe (circled)

These sensors were calibrated at Warwick HRI prior to their installation in May.

Energy use was recorded on the right hand side of the path in blocks 5 (deleafed) and 6 (control) using heat meters. The readings from heat meters were automatically recorded and logged by the control computer.

Figure 8. Heat meter for block 5

Water uptake in blocks 5 (deleafed) and 6 (control) was calculated in 3 ways:

1. As in 2009, using a drain measurement equipment (tipping spoon), manufactured by Priva. A separate unit was installed on the right hand side of the path in both blocks and recorded the run-off from ten plants in each block.

2. New in 2010, using measurement equipment supplied by Hortitechnic. A separate unit was installed in both blocks which measured the application and drain for a whole row. All data was recorded and logged by a separate PC.

3. By manual measurement. Application volume was measured from one dipper in each block and the drain from four plants was captured in a tray and the volume measured at the end of each day.

The nursery was visited throughout the project by various staff from FEC, Warwick HRI, ADAS and Rob Jacobson during the growing season in order to check that the equipment (measuring boxes, heat meters and irrigation) were working properly and to carry out various tests and measurements as required.

Figure 9. Priva tipping spoon (left) and the end of the Martin Drop drain equipment (right)

Crop and yield recording

The yield (class 1, class 2 and waste) was recorded for each crop worker and analysed by block (deleafed and control) in order to statistically compare results. Nursery staff also kept crop records which included weekly growth (stem length), number of flowers, number of fruits set, and the number of fruits cut. These data were analysed using a statistical analysis programme, ANOVA.

In addition to nursery records, as a cross check, plant heights were recorded on two occasions, on 6 July (in week 27) and on 10 August (in week 32), by staff from FEC and Warwick HRI. A minimum of 20 plants were recorded in each block.

Disease monitoring

The crop was examined for disease on three occasions:

1. 27 May (in week 21 before the start of deleafing)
2. 18 August (in week 33 during deleafing)
3. 13 October 2010 (in week 41 after the completion of deleafing)

Rows were walked and each head was examined for stem disease, from the stem base to around 2 m high, from one pathway. The number of spreading lesions and the number of missing plants were counted.

On 25 August (in week 34), around 100 visibly healthy class 2 fruit were collected from each treatment and examined in the laboratory the following day for visible *Fusarium* sp. growth on the seed or internal fruit wall. Nursery records on fruit waste by crop area were also examined.

A sample of four spreading stem lesions was collected on 13 October (in week 41) and tested for fungal pathogens in the laboratory. Tissues were incubated in damp chambers and the resultant fungal growth examined to determine identification.

No fungicides were applied to the crop for control of stem or fruit diseases. Unlike in 2008, nursery staff did not do any cutting-out of stem wound sites with browning suspected to be possible Fusarium infection.

Pest monitoring

Numbers of pest and beneficial species were estimated on four occasions:

1. 8 July (in week 27),
2. 29 July (in week 30),
3. 31 August (in week 35),
4. 12 October 2010 (in week 41).

The primary objective of the first assessment was to provide a baseline of activity for the trial and to check for hot spots of pest activity that may override the main variables in the trial.

There were 160 sample stations per block per assessment date. At each sample station, leaves were examined at three positions in the crop canopy, i.e. upper, middle and lower. From 29 July onwards, samples could only be taken from the upper and middle canopy in blocks 4 and 5. On each date, the numbers of all key pest and beneficial species were recorded separately from each leaf position at each sample point.

Results

Environment

Outside environmental conditions

Figure 10 shows the average outside temperatures achieved in 2009 and 2010, Figure 11 shows the radiation achieved in 2009 and 2010.

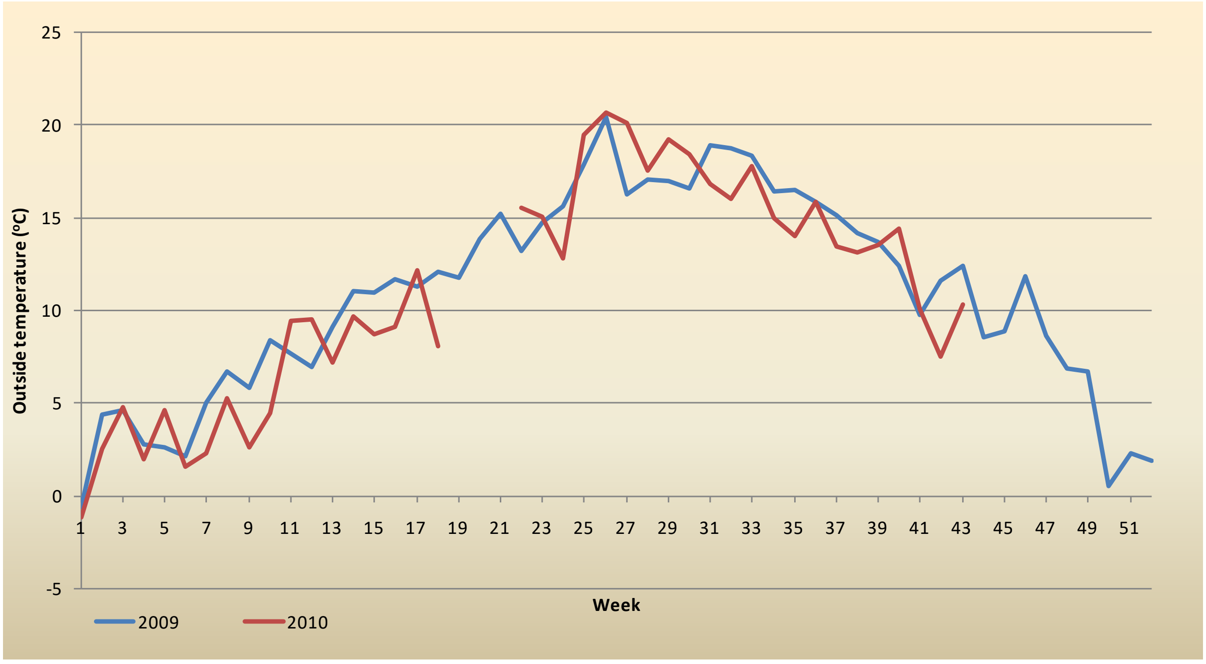

Figure 10. The average weekly external air temperature in 2009 and 2010

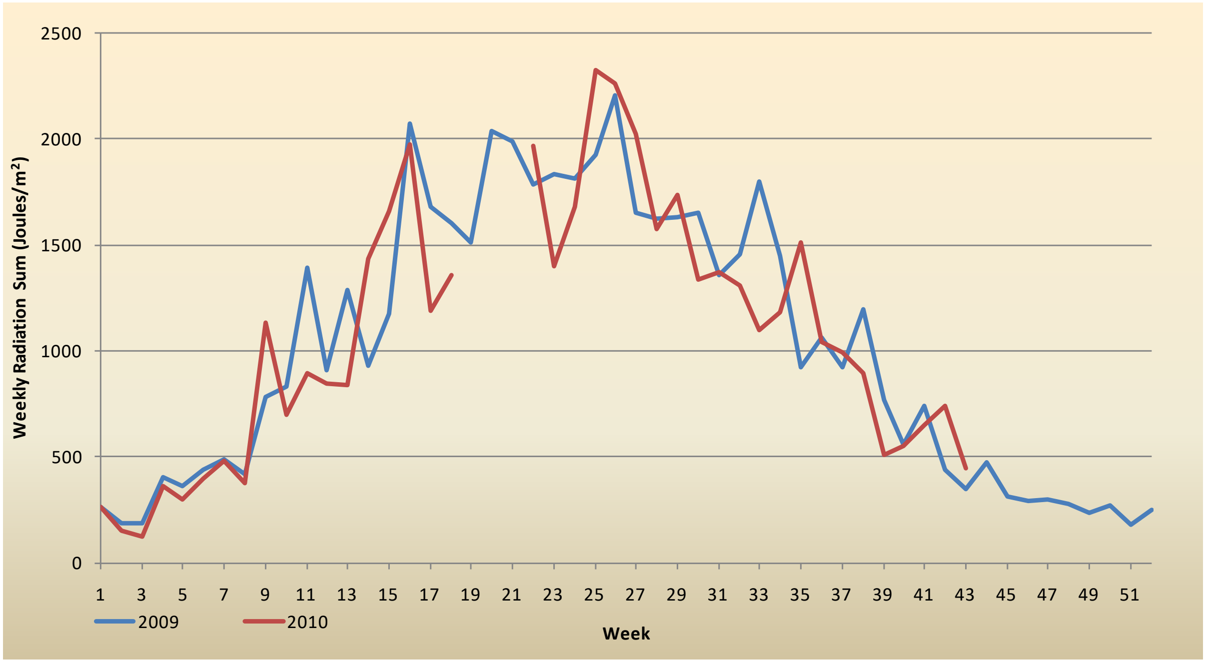

Figure 11. The average weekly radiation sum achieved in 2009 and 2010

Figures 10 and 11 show that the weather conditions in 2010 were similar to the previous years. This means that the data is comparable to the previous year's project and that there were no extenuating circumstances that make 2010 year a special case.

Greenhouse Temperatures

In the 2009 experiment block 6 showed lower temperatures than block 5, (in 2009 block 6 was deleafed and block 5 was the control). The differences started to be clearer at around week 24, when the deleafing treatment started. Temperatures in block 6 were also lower in 2007 and 2008 (see HDC PC 285 Final Report 2010).

Figures 12 to 13 show the air temperatures measured by the **independent sensors** in 2010. These are represented by weekly averages, the arrows indicate the weeks that deleafing took place.

Air temperatures were lower in block 6 (control) than in block 5 (deleafed), both at the left and right hand side of the path, and at the top and bottom of the canopy. The difference between blocks 5 (deleafed) and 6 (control) was between 0.2 and 0.3 °C before the start of the deleafing treatment. A similar difference was maintained after the start of deleafing, except at the top right hand side, where the difference increased to 0.6 °C (see Table 8).

Given the 2010 results it therefore appears that the temperature differences between the blocks 5 and 6 were due to inherent differences between the blocks rather than to the effect of deleafing.

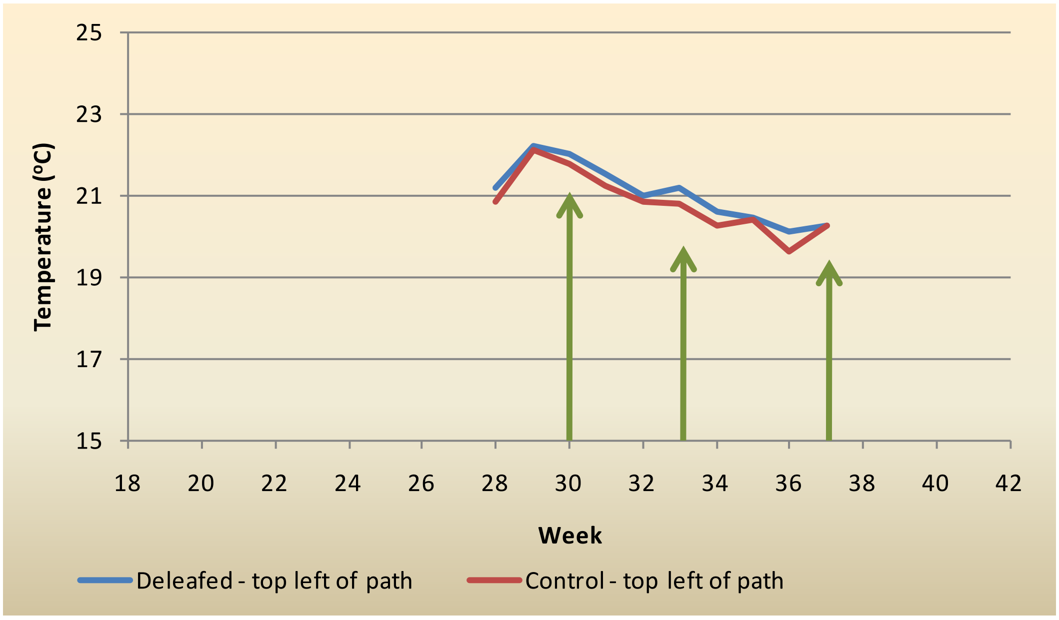

Figure 12. Independent sensors at the top of the canopy to the left of the path

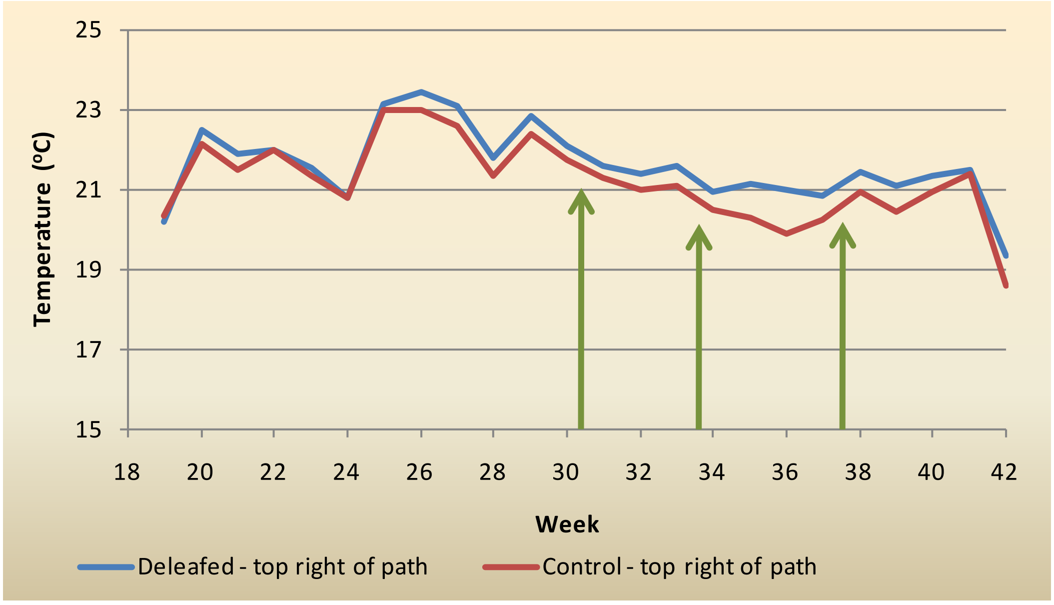

Figure 13. Independent sensors at the top of the canopy to the right of the path

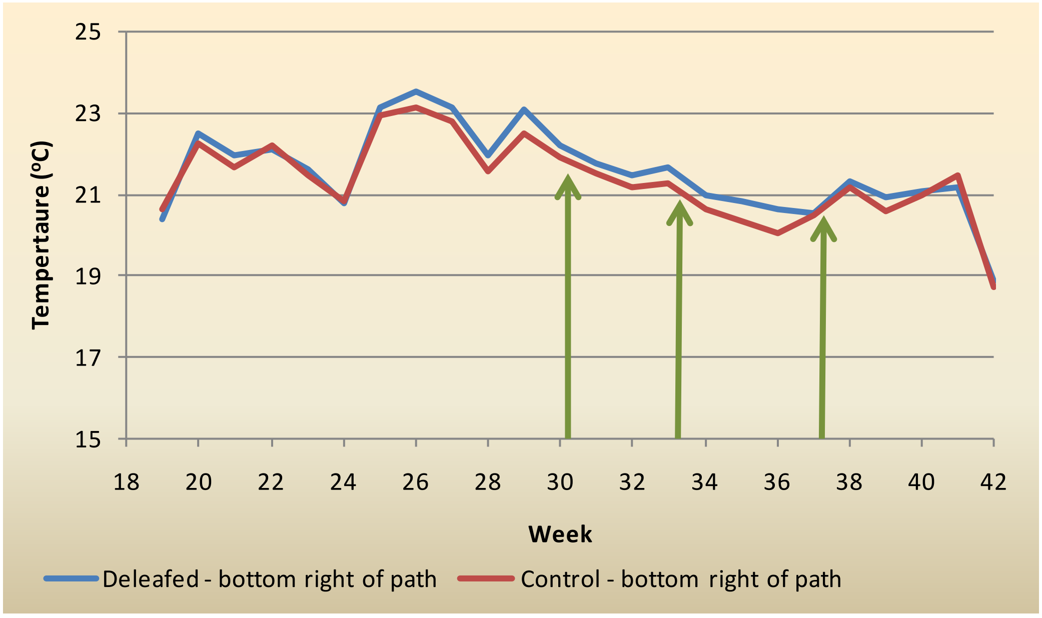

Figure 14. Independent sensors at the bottom of the plant to the right of the path

Table 8. Averages of temperature and relative humidity recorded by independent sensors before and after the deleafing treatment started at the top or bottom of the canopy, right (RS) or left (LS) hand side of the path

	Temperature (ºC)		Relative humidity (%)	
	Weeks 18-30	**Weeks 30-42**	**Weeks 18-30**	**Weeks 30-42**
Block 5 Top LS	22.1	20.8	N/A	N/A
Block 6 Top LS	21.9	20.6	N/A	N/A
Block 5 Top RS	22.0	20.9	73.3	79.6
Block 6 Top RS	21.8	20.3	72.8	79.2
Block 5 Bottom RS	22.1	20.7	71.1	76.4
Block 6 Bottom RS	21.9	20.5	71.4	79.2

Figures 15 and 16 show the air temperatures as measured by the **Priva measuring boxes**. At the beginning of the season, the temperatures recorded in block 5 (deleafed) and block 6 (control) were very similar. After week 26, temperatures in block 6 (control) were lower than in block 5 (deleafed), except at the left hand side of the path, where block 6 (control) showed a higher temperature than block 5 (deleafed) from week 34 (Figure 15). This can be explained by the fact that the Priva sensor in block 6 (control) drifted out of calibration at this point and it read a temperature higher than the independent sensor (1.0°C difference for a period of 40 days after the drifting started at which point the independent sensor was removed).

The difference between block 5 (deleafed) and 6 (control) at the right hand side of the path (Figure 16) was greater when measured by Priva sensors than by the independent sensors, especially after week 26 (see Table 9). Priva sensors in block 5 (deleafed) tended to read slightly higher than the independent sensor in this measuring box. This also happened in 2009.

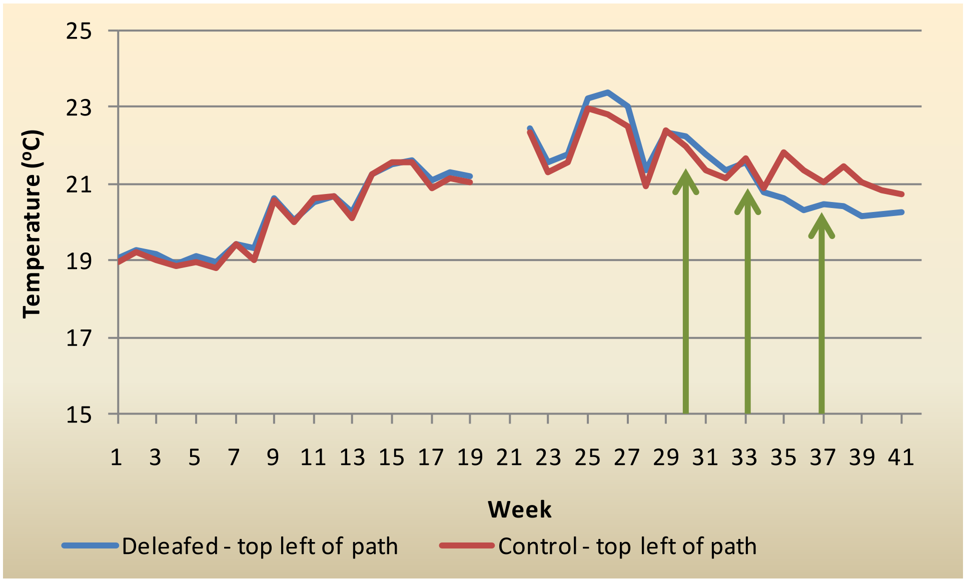

Figure 15. Air temperatures measured by the Priva measuring boxes at the top of the canopy to the left of the path

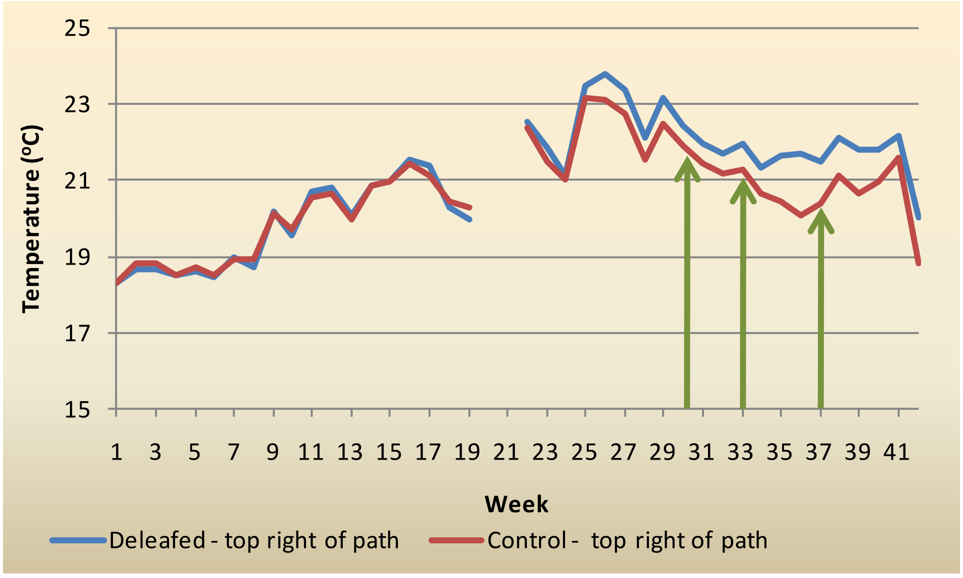

Figure 16. Air temperatures measured by the Priva measuring boxes at the top of the canopy to the right of the path

Table 9. Averages of temperature and relative humidity recorded by the Priva sensors before and after the deleafing treatment started at the top or bottom of the canopy, right (RS) or left (LS) hand side of the path

	Temperature (°C)		Relative humidity (%)	
	Until 26 July	After 26 July	Until 26 July	After 26 July
Block 5 Top LS	22.3	20.2	76.7	83.0
Block 6 Top LS	22.0	20.6	76.3	80.7
Block 5 Top RS	22.4	21.4	75.4	81.8
Block 6 Top RS	22.0	20.5	77.2	83.9
Block 5 Bottom RS	22.3	20.9	75.9	79.1
Block 6 Bottom RS	22.1	20.6	74.0	81.7

On balance the independent sensors are more accurate a representation of conditions in the greenhouse than the Priva Measuring boxes. Unfortunately because the measuring boxes are also used for control they will always represent the conditions that are expected i.e. if they are controlling to an air temperature of 22°C they will show this value even if the air temperature in reality is 24°C because they directly influence whether pipe heat is applied or not. This makes it very difficult in certain circumstances to identify when a measuring box has drifted out of calibration and the importance of regular measuring box checks cannot be underestimated.

Humidity

The average weekly relative humidity and humidity deficit on the right hand side of the path in block 5 (deleafed), and block 6 (control), **using independent RH sensors** are shown in Figures 17 - 20. The arrows indicate the weeks in which deleafing took place.

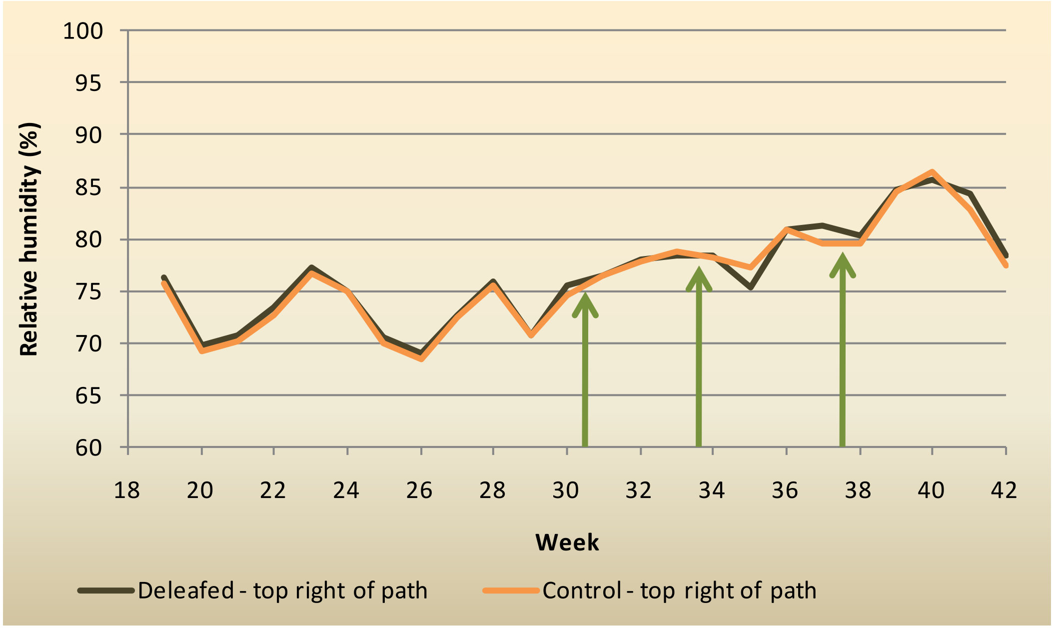

Figure 17. The average weekly relative humidity at the top of the canopy to the right hand side of the path

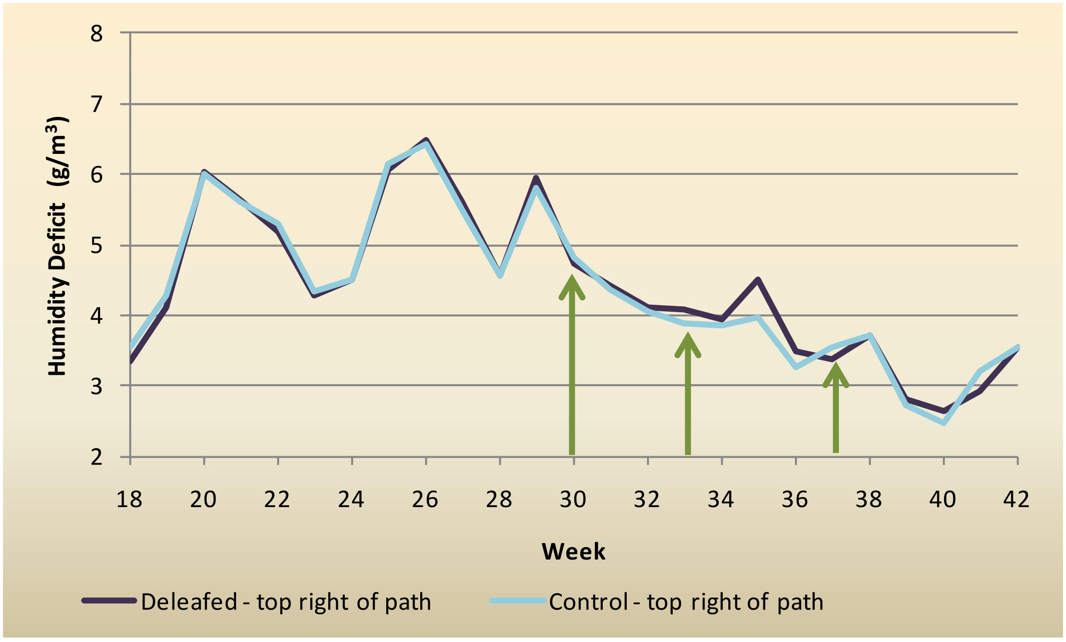

Figure 18. The average weekly humidity deficit at the top of the canopy to the right hand side of the path

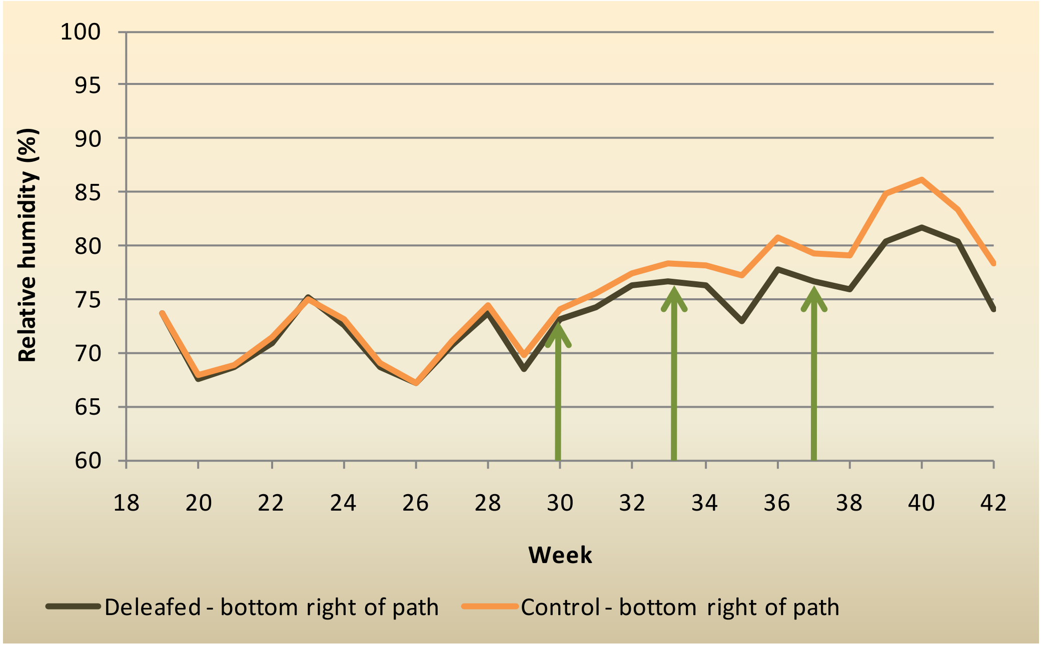

Figure 19. The average weekly relative humidity at the bottom of the plant to the right hand side of the path

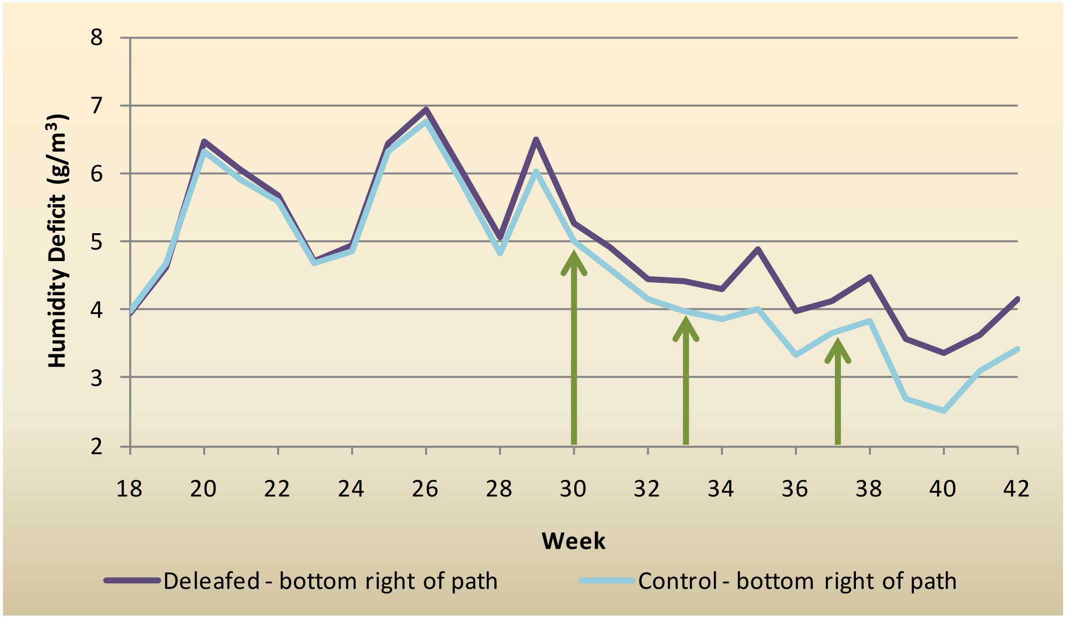

Figure 20. The average weekly humidity deficit at the bottom of the plant to the right hand side of the path

The data from the **independent humidity sensors** shows a very similar RH at the top of the canopy on the right hand side in both blocks. There was no clear difference in RH after the deleafing treatment started.

Prior to deleafing the RH in both blocks at the bottom of the plant were very similar however after deleafing started the RH at the bottom in block 5 (deleafed) was on average 3% lower. This reduction in the RH at the bottom of the canopy in the deleafed block appears to be related to the deleafing treatment.

Humidity at the top of the crop during daytime hours is often more driven by weather effects than heating through the pipe rail heating system. However, the humidity at the bottom of the canopy can be influenced by application of pipe heat. These graphs show that without affecting the pipe heat the humidities can be bettered by deleafing. It therefore also follows that a reduction in pipe heat would be possible and still achieve acceptable humidities. This was not tested as part of this project.

Figure 21 shows the weekly average RH of the two blocks at the top of the canopy to the left hand side of the path as measured by the Priva measuring boxes. This shows a very similar RH between the blocks until week 33 when block 5 (deleafed) starts to show an increased RH.

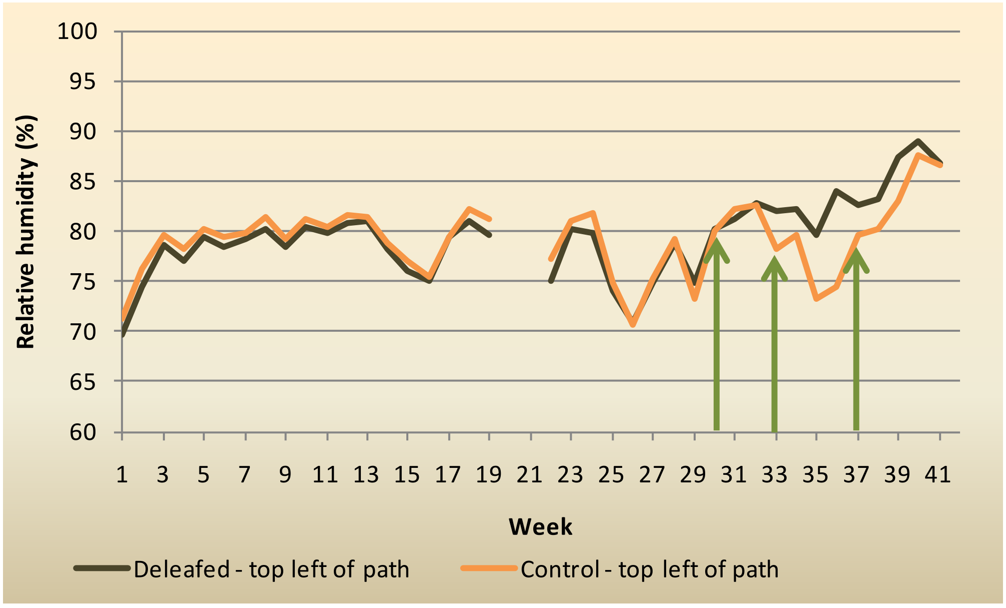

Figure 21. Differences in RH measured by the Priva at the top of the canopy on the left hand side of the path

The difference is attributed to a problem with the sensor especially since the air temperatures also shows a similar pattern (Figure 15). Therefore no conclusions can be drawn from this data except for showing the importance of maintaining the measuring boxes.

As part of this project the measuring boxes were checked at every visit by Farm Energy, this was done by removing the wicks from the wet bulb temperature probe and ascertaining that both the dry and wet bulb temperature probes then read the same.

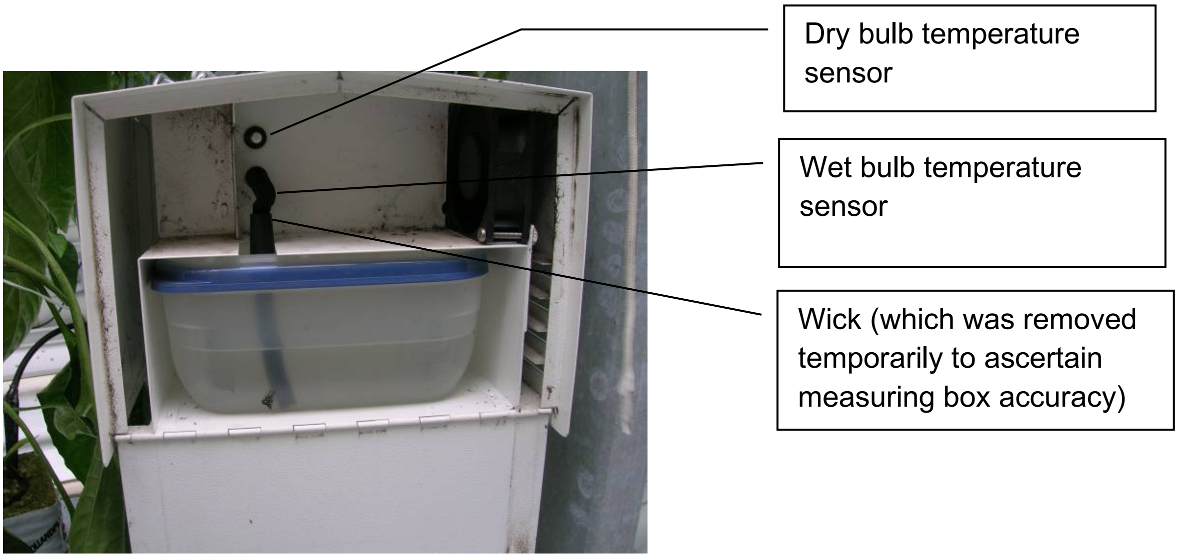

Figure 22. Measuring box showing dry and wet bulb temperature sensors

In May 2010 this was done and it was discovered that the sensors at the top right hand side of block 5 (deleafed) showed a 0.3°C difference, which could account for around a 2.5% difference in RH. As a result the dry temperature bead in block 5 (deleafed) was changed the following week. A sensor also appears to have drifted out of calibration in block 6 (control) from week 33. Unfortunately this was not noticed at the time.

Carbon dioxide concentration

Figure 23 shows the average weekly (daytime) CO_2 concentrations achieved in each block.

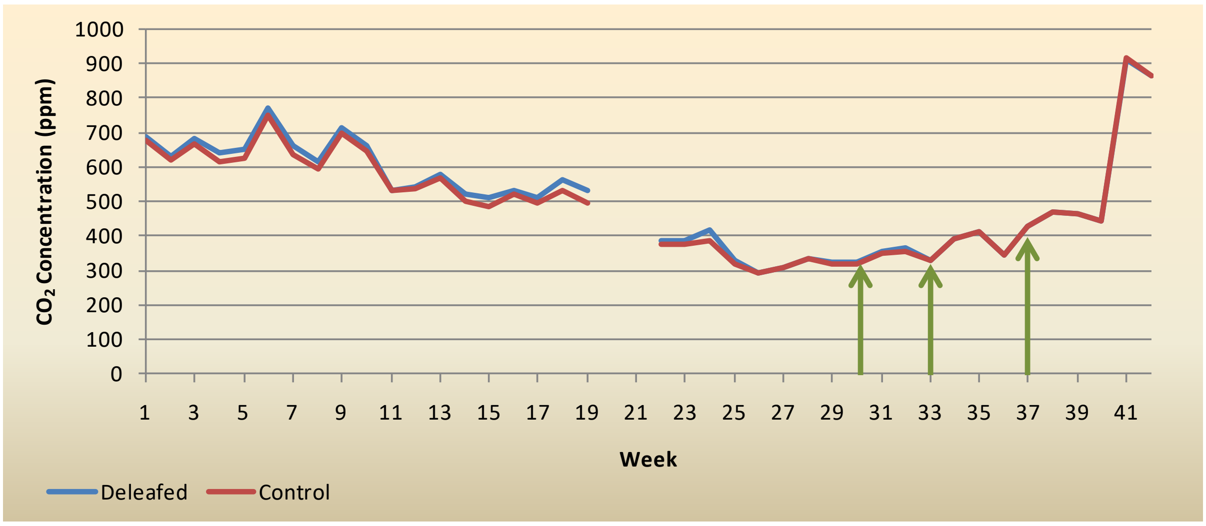

Figure 23. The average weekly CO2 concentrations recorded by the Priva climate control computer in blocks 5 (deleafed) and 6 (control).

As in previous years, the day time CO_2 concentration was slightly higher in block 5 (deleafed) compared with block 6 (control) (Figure 23), especially early in the season, before the start of deleafing (531 ppm and 516 ppm respectively).

After deleafing started the average in both blocks was the same (471 ppm and 470 ppm respectively). Therefore, there is no significant effect on CO_2 concentrations from deleafing as suggested at the end of 2009 experiment.

Energy use

Figure 24 below shows the weekly variation in energy consumption between the two blocks in kWh/m². Figure 25 shows the percentage difference between the blocks with a positive number reflecting a period of energy saving in the deleafed block.

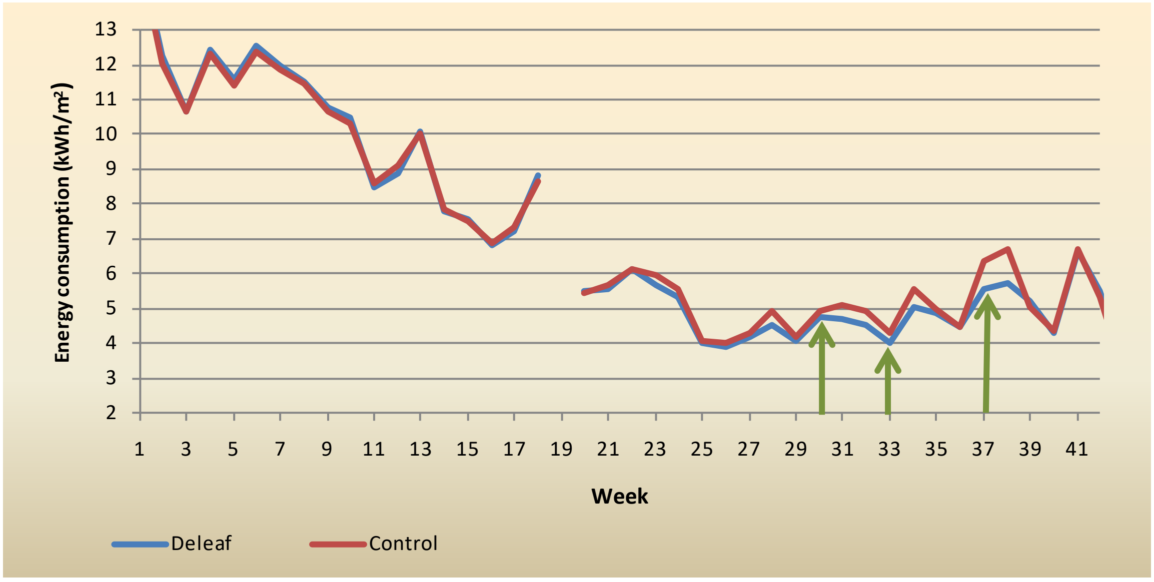

Figure 24. Pattern of daily energy in blocks 5 (deleafed) and 6 (control). The arrows indicate the times of deleafing in block 5.

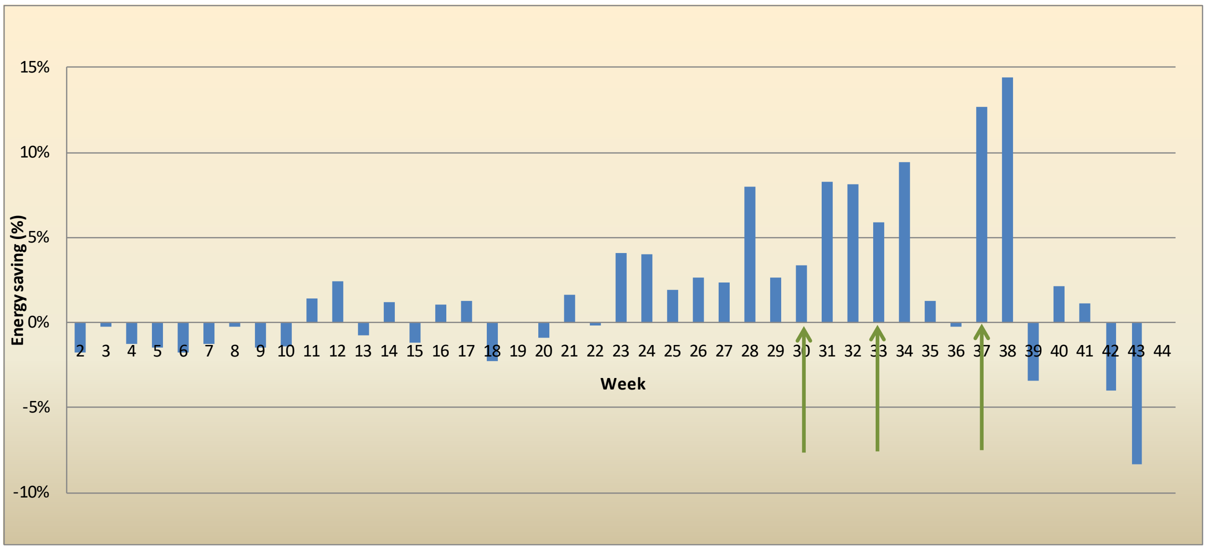

Figure 25. Percentage energy saving (positive values) in the deleafed block by week

The energy used in blocks 5 (deleafed) and 6 (control) was very similar up to the beginning of week 23. From that point on, up to the start of deleafing in week 30, the control block used an average 3.8% more energy. The heat requirement for the nursery is controlled by setting pipe rail temperatures. If the flow rates of the pipe rails are different then the quantity of heat will be also different for the same given pipe temperature. During periods of heating for purposes of maintaining temperature this does not have a significant effect because the pipe temperature is allowed to alter according to the required conditions. However when pipe temperatures spend long periods at minimum pipe settings (i.e. a temperature beyond which they are not allowed to fall, typically 35 °C) then different quantities of heat will be applied in each block.

This was the case from week 23 onwards - the pipe rail flow rates were measured at 32.48 m^3/hr and 34.11 m^3/hr for the deleafed and control block respectively. This would mean for periods at minimum pipe the control block will use 4.8% more heat. This explains the measured difference between the blocks of 3.8% between weeks 23 and 29.

From the start of deleafing to week 42, the control block used an average of 4.9% more energy - a difference of 1.1%. Table 10 below shows a more detailed breakdown of the differences in energy consumption by relevant periods in the year.

Table 10. The effect on energy consumptions during relevant periods

	Deleafed kWh/m²	**Control kWh/m²**	**Difference kWh/m²**	**% saving**
Energy consumption - sum from week 1 to end week 22	202.27	201.20	-1.1	-0.53%
Energy consumption - sum from week 23 to end week 29	31.75	33.01	1.3	3.81%
Difference 1st deleafing (week 30 - 32)	*13.97*	*14.95*	*1.0*	*6.60%*
Difference 2nd deleafing (week 33 - 36)	*18.48*	*19.31*	*0.8*	*4.31%*
Difference 3rd deleafing (week 37 - week 42)	*32.97*	*34.54*	*1.6*	*4.52%*
Energy consumption - sum after deleafing started (from week 30 to week 42)	65.42	68.80	3.4	4.91%
Energy consumption as whole season total	299.4	303.0	3.6	1.18%

The data above suggests that the energy saving at the nursery in the 2010 season, for deleafing is 1.18%. This is worth 0.75 kWh/m^2 of the total heat required by the nursery or 0.88 kWh/m^2 of gas (£265 per hectare at 3p/kWh).

Influence of heat destruction

During the experiment the greenhouse blocks were used to destroy heat for the purposes of CO_2 production. Each block was given the same settings to ensure replication however the energy consumptions shown are greater than if energy was being used for climate control alone.

During heat destruction it is difficult to ascertain when environmental conditions are beyond set point expectations and hence when there are differences in energy consumptions between the blocks. Figure 26 shows a typical example of a day when heat destruction is being carried out.

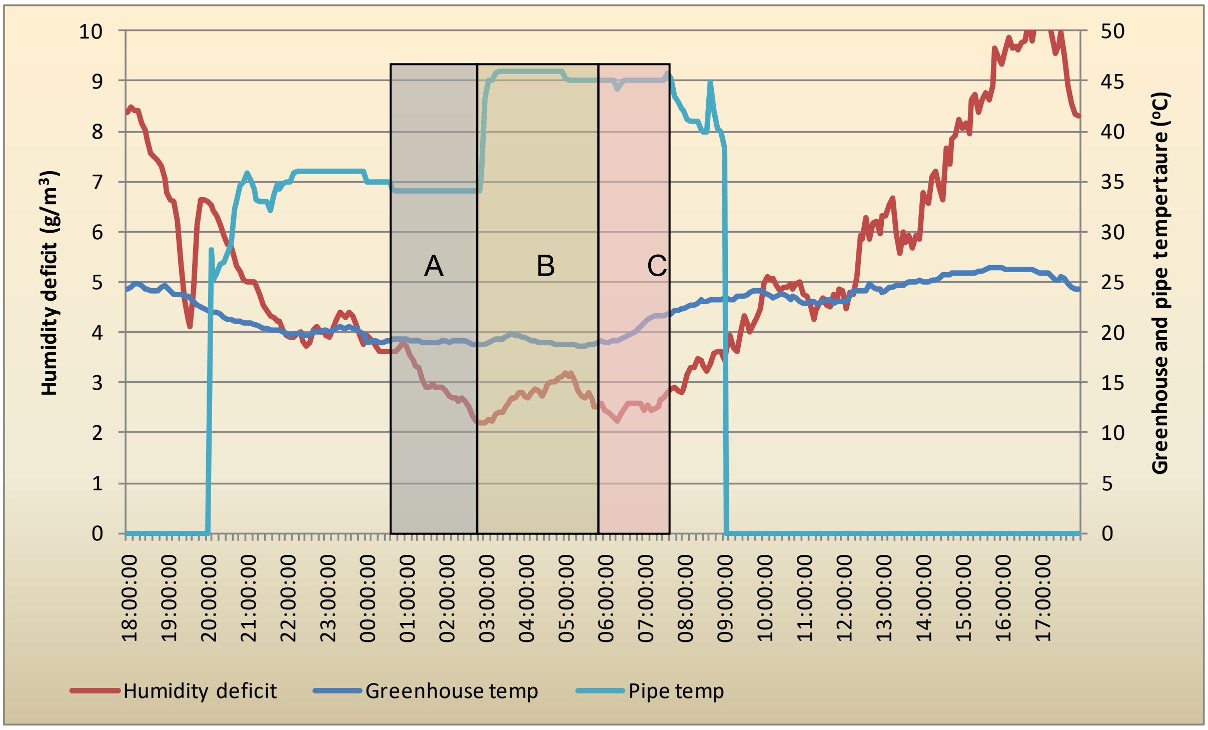

Figure 26. Showing a day where heat destruction was carried out

Region A: Pipe temperature 35 ºC, HD falling, Greenhouse temperature maintained at 19 ºC pipe stays at minimum set point

Region B: Pipe temperature increases to 45 ºC even though environmental conditions are within limits - **heat destruction**

Region C: Pipe temperature maintained at 45 ºC, humidities fall as sun rises, heat is required to maintain conditions. It is during this period that the 1.18% energy saving discussed in the section above will be realised.

Experience suggests that in Region B a minimum pipe temperature of 40ºC would have been adequate. Based on the example above this represents heat destruction of 0.315 kWh/m^2/week worth 0.37kWh/m^2/week of gas. These values cannot be used to determine any saving from deleafing as each block was treated identically.

Influence of humidity on energy consumption

As discussed earlier the humidities of the blocks did not differ at the top of the canopy but there was clear indication of reduced humidities (higher HD's) at the bottom of the canopy. Considering that heating pipe temperatures influence the humidity at the bottom much more than the top (where weather has a bigger influence) it is possible that reduced pipe temperatures could be achieved whilst maintaining set point humidity.

In the case of this nursery, reducing the heating pipe temperature will lead to increased heat destruction at other times and there is therefore no net benefit. If a nursery is not destroying heat then a reduction in average pipe temperatures of 5^{o}C for humidity control seems possible. A 5^{o}C reduction in pipe setting will deliver energy savings of 0.95 kWh/m^2/week of heat or 1.1 kWh/m^2/week of gas. Over the 10 week deleafing period this would represent 9.5 kWh/m^2/year heat which is 3.1%.

Due to the small energy use and the issues surrounding heat destruction it is difficult to provide firm results regarding the energy saving provided by deleafing. The figures above are provided to give an indication of the potential. If we assume these to be correct they suggest that deleafing plants can give an annual saving of 10.25 kWh/m^2 heat (9.5 kWh/m^2 for better humidity control and 0.75 kWh/m^2 for active growing periods) this is 12 kWh/m^2 gas and represents 3.4% of the annual heat demand.

Water use

Martin Drop Drain Water Logger

The primary and best method of recording the change in water use by the plants in each block proved to be the Martin Drop Drain Water Logger (DWL) i.e. the whole row system. This system did however prove problematic on several occasions - largely because of hardware malfunctions which resulted in drain volumes being calculated inaccurately. Unreliable data was therefore deleted and omitted from the analysis.

Figures 27 - 29 show the results of the analysis.

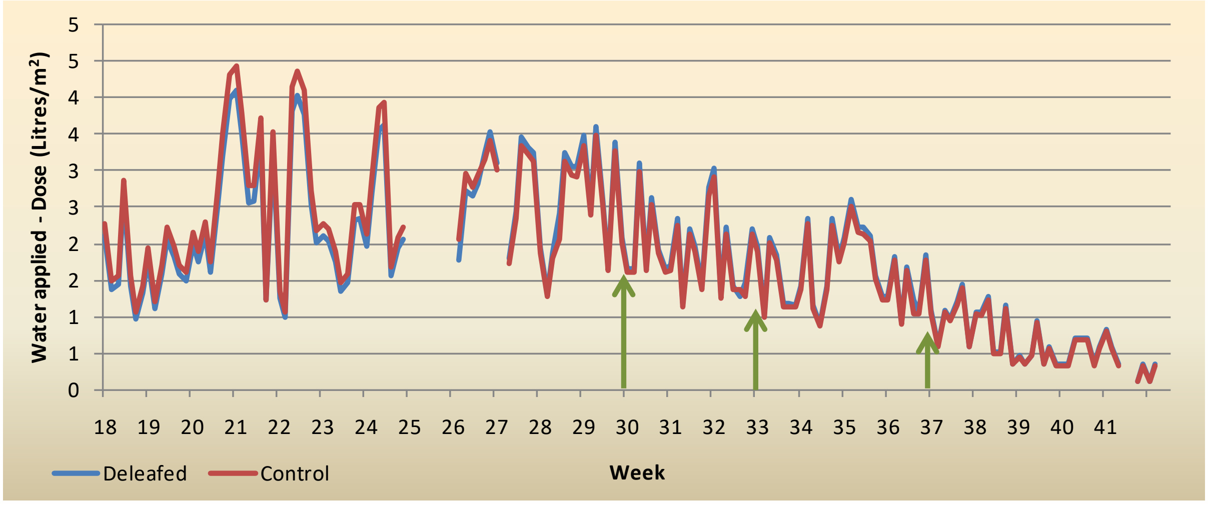

Figure 27. Water applied by week (dose)

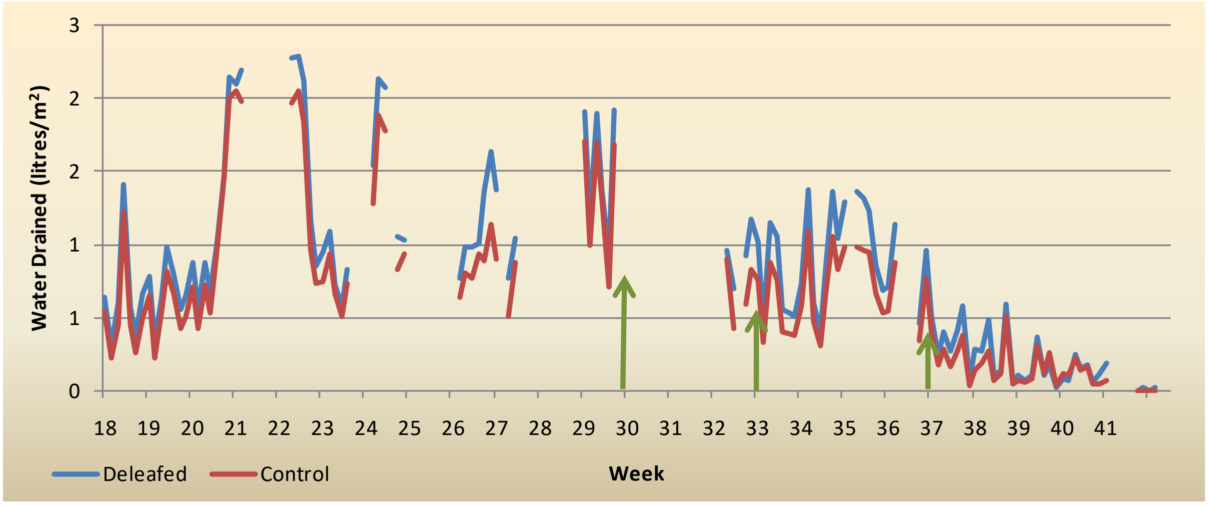

Figure 28. Water drained by week

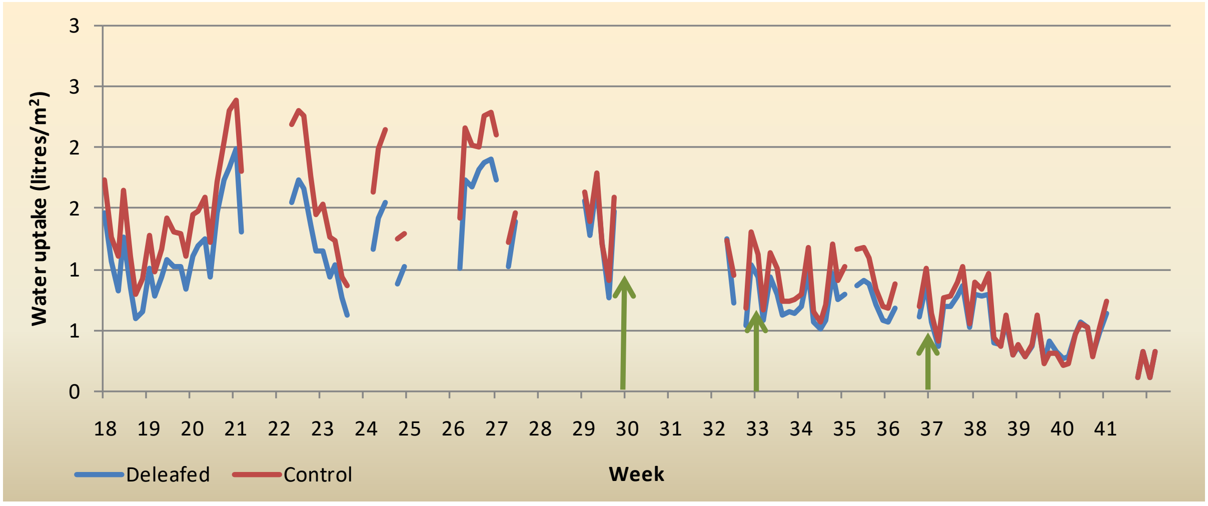

Figure 29. Water uptake by week

While the uptake in block 5 (deleafed) might have been expected to be reduced due to the reduced leaf area, this was not supported by the data. Block 6 (control) showed a greater uptake than block

5 (deleafed) during the whole season. Before the start of deleafing the difference was on average 25%. Once deleafing started, the difference, instead of increasing, was reduced to 12%.

There is no considered mechanism by which deleafing could contribute to increased water uptake and it is therefore concluded that this data is unreliable.

Tipping spoon and manual reads

As discussed in the previous year's report the data from the tipping spoon comes from a very small sample of plants. If any of these show problems (broken heads etc) the data becomes meaningless. Similarly the data from the manual readings taken by the nursery staff suffers the same issues. This data has therefore been omitted from the analysis.

The unreliability of the equipment has meant that there is no firm conclusion as to the water saving or lack thereof from deleafing.

Long term water analysis

Long term water data was made available by the nursery. This was given as water meter readings from the irrigation rigs as recorded by the water control system. Table 11 shows the results of analysis of this data. Initial indications are that 2009 and 2010 water consumption was much lower than in previous years.

Table 11. Showing the reduction in consumption as annual totals and as total volume applied per m^2 and per joule of light

Year	Volume recorded (litres)	Light received (Joules)	Applied volume (litres/joule)	Applied volume (litres/m^2)
2005	41,688,860	361,669	115.27	1,432
2006	42,897,258	370,643	115.74	1,474
2007	43,508,409	365,020	119.19	1,495
2009	39,294,975	377,062	104.21	1,350
2010	31,000,000	363,835	85.20	1,065

The table shows that the water applied was some 11% reduced in 2009 (first year of deleafing) and 29% reduced in 2010 over the 2005-2007 average year. Whilst it may seem that deleafing contributed to this reduction in water use, such a large reduction seems unlikely.

Conversation with the grower at VGN determined that in 2008 and 2009 water use was being tracked more closely and that action was taken to reduce the high levels of drain which had been recorded from the site as a whole. This action together with deleafing the whole nursery to the V (removal of 50 cm of leaf from all plants) from 2008 onwards provides a more logical explanation for the reductions in water consumption than deleafing alone. Figure 30 below shows how the water application varied throughout the years.

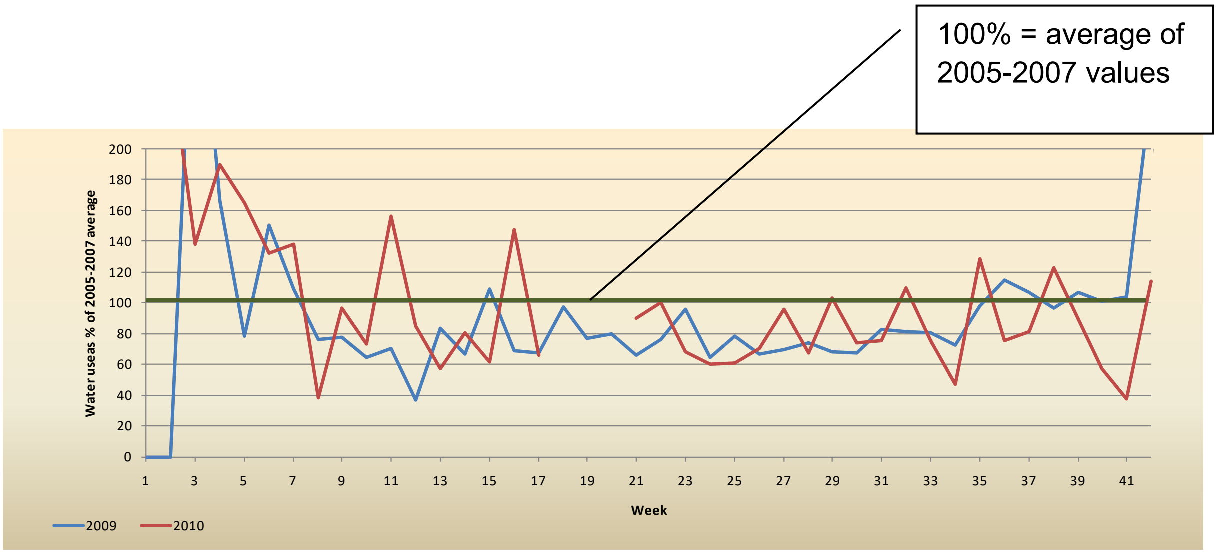

Figure 30. Showing the weekly water use as a percentage of the average year 2005-2007

This data shows the benefit of paying more attention to water application rates. The nursery has managed to achieve a water saving of 300 litres/m^2 which is worth £5,190 per hectare at £1.73 /m^3.

Crop and yield recording

Crop recording data

Figure 31 shows the weekly growth of the plants in each block as recorded by staff at VGN.

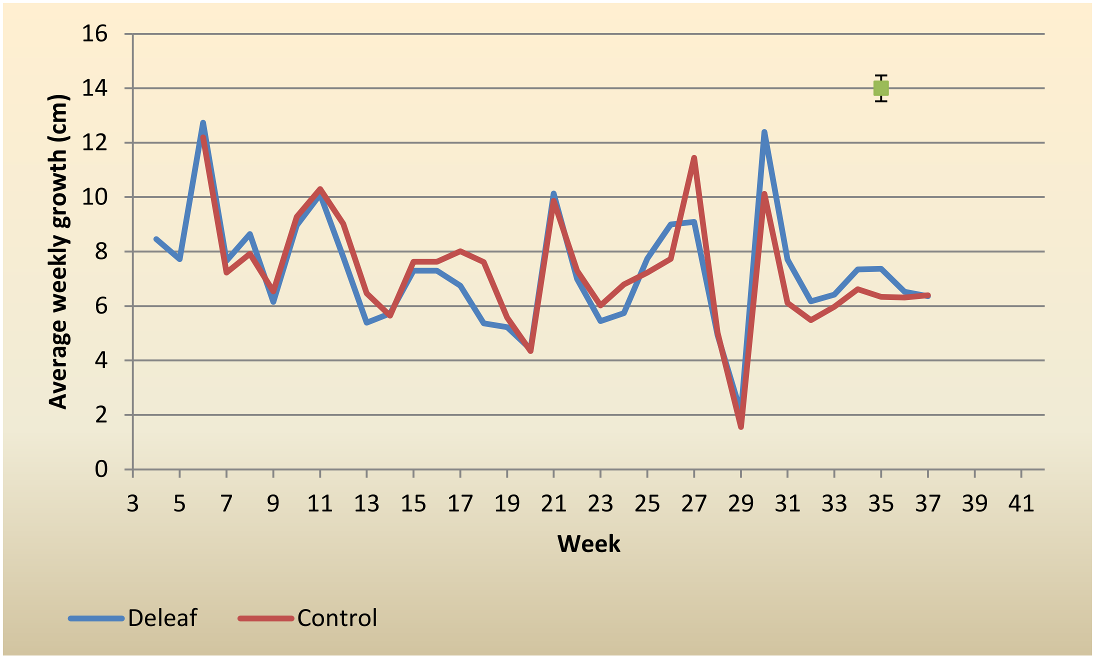

Figure 31. The average growth per week for 20 control shoots and 40 deleafed shoots. The bar represents a pooled standard error of difference for comparing two means in any given week.

There was very little evidence for any significant effect of deleafing on weekly growth (increase in plant height as recorded by staff at VGN (Figure 31)). This was supported by the crop heights recorded by staff from FEC or Warwick HRI; the average height of the control and deleafed plants was 261 cm on 6 July 2009, before the treatment started, and 295 cm and 292 cm on 10 August 2009 (SEM were 1.7 and 1.9 respectively).

Figures 32 - 34 show the results of the crop recording as carried out by the staff at VGN. This crop recording showed that deleafing did not have a significant impact ($P > 0.05$) on the total number of flowers (Figure 32), fruit set (Figure 33) and fruits cut per plant (Figure 34) over the course of the growing season or indeed in any given week after the treatment started.

In all 3 graphs the bars to the top right represent a pooled standard error of difference for comparing two means in any given week.

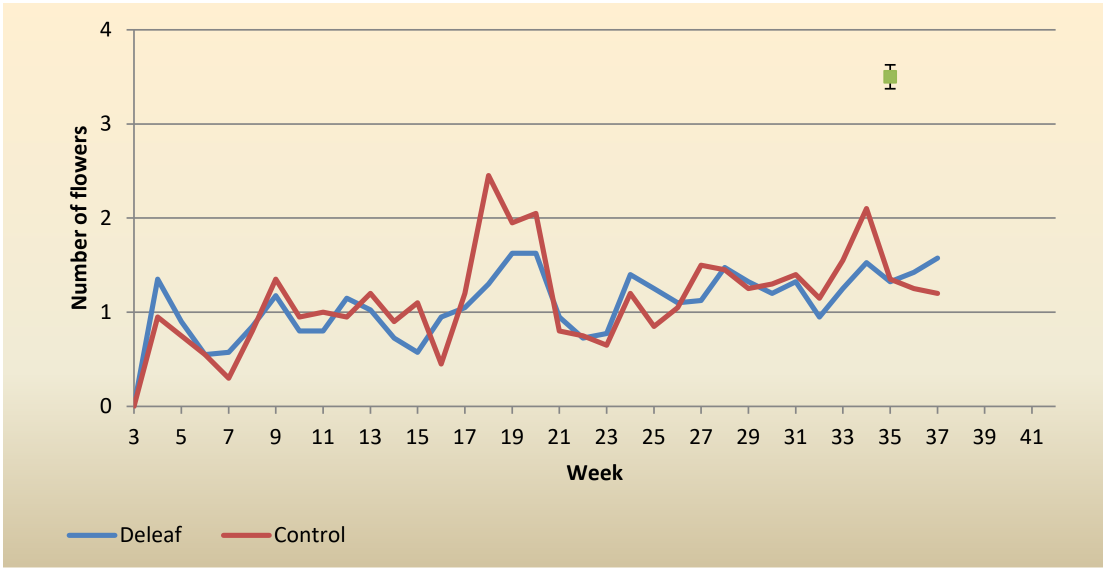

Figure 32. Number of flowers (average for 20 control shoots and 40 deleafed shoots)

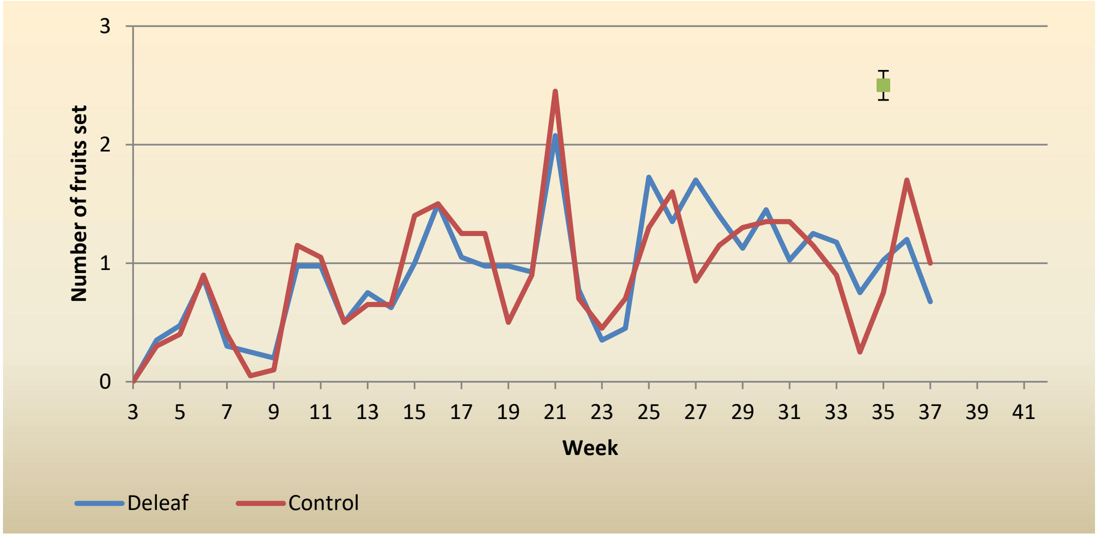

Figure 33. Number of fruits set (average for 20 control shoots and 40 deleafed shoots)

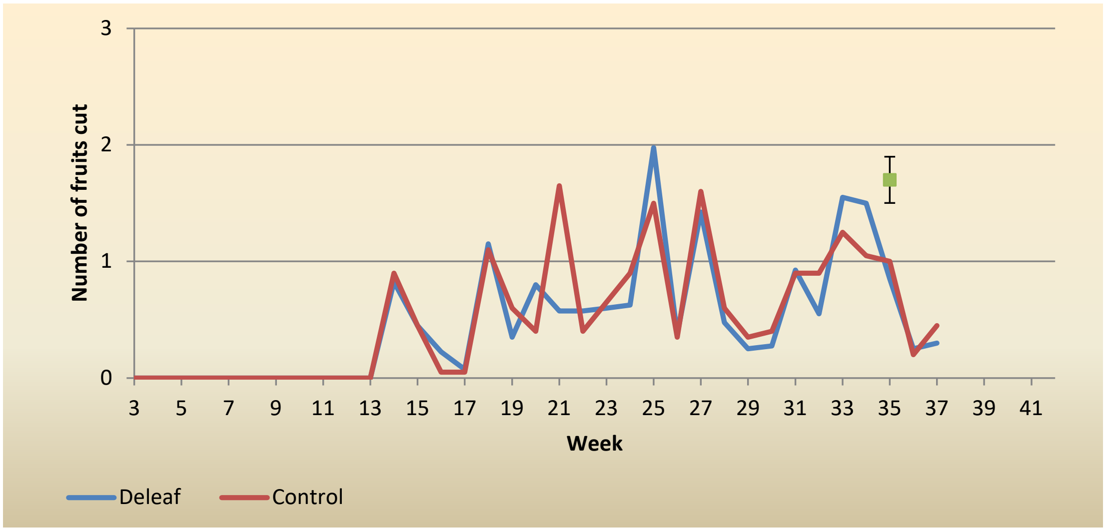

Figure 34. Number of fruits cut (average for 20 control shoots and 40 deleafed shoots).

Yields

In 2010 there were five crop workers in blocks 4, 5 and 6, including two workers who were assigned to work in more than one block. As in 2009, the yield from the worker who covered blocks 5 (deleafed) and 6 (control) was split accordingly, with the Monday's picks assigned to block 5 (deleafed) and the remaining picks to block 6 (control). The yield from the worker who picked in blocks 4 and 5 (both deleafed) was left intact. The weekly yields are shown in Figures 35 (Class I fruits) and 36 (Class II fruits) - waste fruits are considered under the disease section of the report as the cause was predominantly due to *Fusarium* sp.

There was no true replication of deleafing treatments, and therefore, to enable some statistical analysis of the weekly and cumulative yields, the yields per worker were used as pseudo replicates.

- The cumulative yields of Class I fruits in the control and deleafed areas were 26.1 and 26.4 kg/m2 and the difference was not significant (P > 0.05).
- Similarly the difference in Class II yields was insignificant (P > 0.05) with an average of 1.0 and 0.9 kg/m2 in the control and deleafed areas respectively.

Figure 35 shows the weekly yield of Class I and Figure 36 the yield of Class II fruits for each block.

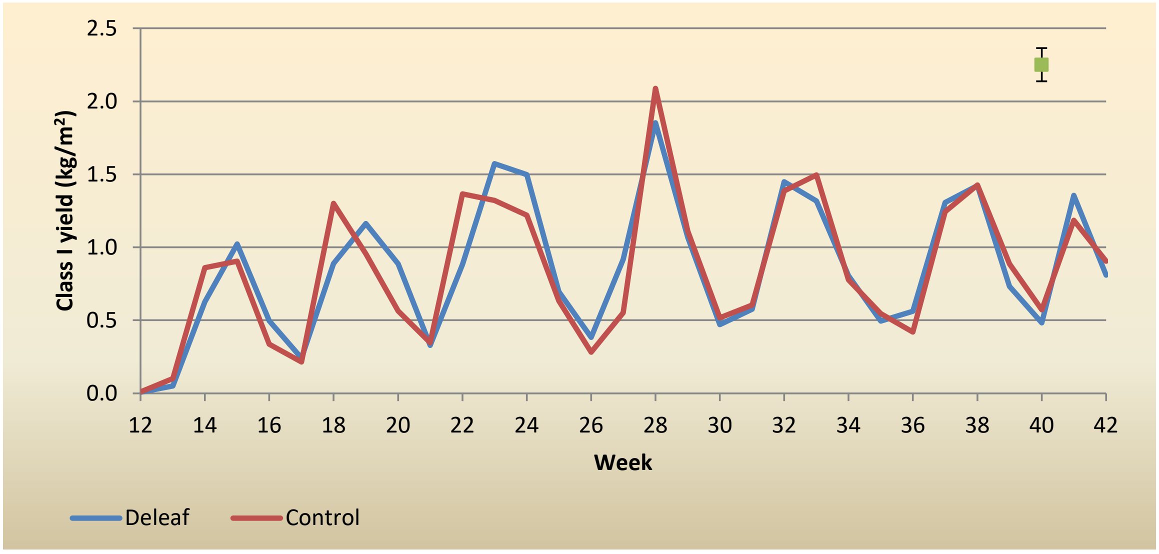

Figure 35. Class I yield. The bars represent a pooled standard error of difference for comparing two means in any given week

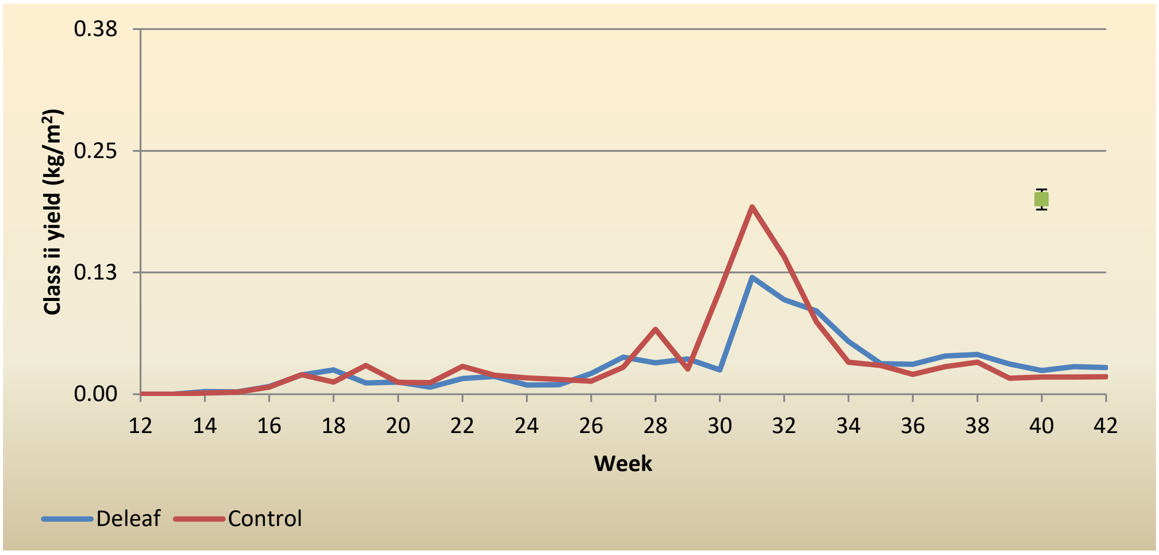

Figure 36. Class II yield. The bars represent a pooled standard error of difference for comparing two means in any given week

Figures 35 and 36 above show that there was little evidence for any impact of deleafing on the weekly pattern of yields; no differences (*P* < 0.05) were found on a weekly basis in the yield of

Class I fruits after deleafing started. For class 2, the control area produced more Class II fruit than the deleafed area in weeks 30, 31 and 32. This does not appear to be related to deleafing, since it coincided with the start of deleafing and any effects would be expected to be seen later than this.

Labour

There is an increased labour requirement for deleafing. This was done in 2010 by permanent staff for the deleafing to the V and the fourth deleafing and by temporary staff for the second and third deleafing.

Each deleafing beyond deleafing to the V, took an average of 1.4 minutes/m^2 (a total of 4.2 minutes/m^2 for all three) which cost the nursery £0.30/m^2.

A labour saving can be realised by the reduction in time taken to remove the crop at the end of the year. This was reported as 180 hours saving for the whole nursery equivelant to £0.05/m^2.

Disease monitoring

Overall, the results confirm those found in 2009 and indicate that deleafing of the lower portion of pepper stems neither increases nor reduces the incidence of Botrytis stem rot or Fusarium internal fruit rot.

Stem lesions

Spreading lesions on the stem were first observed on 18 August (in week 33), when one lesion was found in the deleafed monitored rows and none in the control rows. At this time there were 10 missing heads in the deleafed monitored rows and 16 in the control rows. The crop was deleafed to around nine nodes above the V (i.e. where the main stem splits into three heads).

When assessed on 13 October (in week 41), there were a total of three stems with a spreading stem lesion in each of the deleafed and control monitored rows. Leaves were wilting badly on four of these stems. One lesion was at the V, the others were around 1-2 m above the V.

The number of missing stems in each of these areas, assumed to be due predominately to stem lesions, was 28 in the control area and 20 in the deleafed area. The number of stems with spreading lesions, and the numbers of stems with spreading lesions + missing stems per quarter row were examined. The number of stems with spreading lesions per quarter row (84 stems originally) ranged from 0.1 to 0.4; the combined number of stems with a spreading lesion + missing stems per quarter row ranged from 1.0 to 2.5 (out of 84 stems originally). There was no significant effect from deleafing or row position on the number of spreading stem lesions or the combined totals of stem lesions and missing stems (Table 12). An interaction effect between deleafing treatment and row position (ridge or gutter) was not quite significant at the 5% level. At this time the crop was deleafed to 11 nodes above the V.

Isolation tests confirmed that the majority of stem lesions observed in crops were associated with *Botrytis cinerea* (3 out of 4 lesions tested), while one was associated with *Fusarium* sp. As in 2008 and 2009, the *Fusarium* sp. isolated from stems and fruit appeared identical in culture and was probably F. oxysporum or a closely-related species.

Table 12. Effect of deleafing and row position on occurrence of spreading stem lesions, or missing stems on pepper, cv. Cupra – 13 October 2010, a = 28 cubes and 84 stems per quarter row length.

Factor and treatment	Total number spreading lesions per quarter row [a]	Number spreading lesions + dead + missing stems per quarter row
Deleafing		
Control	0.2	1.4
Deleafed	0.2	1.9
Significance	NS	NS
LSD	-	-
Row position		
Gutter	0.3	1.8
Ridge	0.1	1.6
Significance	NS	NS
LSD	-	-
Interactions		
Control – gutter	0.4	1.0
Control – ridge	0.0	1.9
Deleaf – gutter	0.3	2.5
Deleaf – ridge	0.1	1.4
Significance	NS	0.061
LSD	-	1.48

Internal fruit rot

Blossom end rot was evident on some fruit at the crop inspection on 18 August (in week 33). Laboratory examination of visibly sound fruit collected on 25 August (in week 34) revealed that many were infected internally by *Fusarium* sp. (Table 13). The proportion of infected fruit was 40% in the control area and 45% in the deleafed area. Most infection was found on the seeds. None of the fruit had a small hole at the base, a symptom found in some fruit in 2009.

These results confirm those of 2009. There was no effect from deleafing, either beneficial or adverse, on the incidence of stem lesions or internal Fusarium fruit rot in pepper. An even lower level of stem disease occurred on a replicated, randomised experiment on deleafing in 2008 and it was not possible to draw any conclusions from that experiment.

Table 13. Effect of deleafing and glasshouse block on Fusarium internal fruit rot in pepper, cv. Cupra – 2010

Location of Fusarium in Fruit	**% Fruit affected**		
	Block 4 (Deleafed)	**Block 5 (Deleafed)**	**Block 6 (Control)**
Seed	43	42	39
Wall	1	1	0
Seed & fruit wall	1	2	1
Total	45	45	40

Nursery fruit wastage

The proportion of total fruit yield classed as wastage from nursery records, reported to be due primarily to Fusarium external and internal fruit rots, was examined in each block for the periods up to, during and after the start of deleafing (Table 14).

There was a large and significant ($P<0.05$) difference in wastage between the two deleafed glasshouse blocks (blocks 4 and 5) during the season with twice as much wastage in block 4 (1.2%) as in block 5 (0.6%). This was largely due to the difference during weeks 27-37 when the crop was being deleafed. Fruit wastage in block 6 (control) was similar to that in block 5 (deleafed).

It is difficult to draw conclusions as to the effect of deleafing on fruit wastage due to the large difference between glasshouse blocks (4 and 5, both deleafed) in which crop treatment was identical.

Interestingly, the same pattern of greatest wastage in block 4 also occurred in 2009, when blocks 4 and 5 were controls (not deleafed blocks); and in 2007 when blocks 4 and 5 were control and block 6 was a summer shading block. This strongly indicates that block 4 has a different environment to blocks 5 and 6. The grower reported that block 4 tends to be more humid than the other sections within the glasshouse and to a certain extent warmer due to the orientation of the rows in relation to how the sun tracks during the day. The effect is seen more during the summer than any other time.

Table 14. Effect of deleafing and glasshouse block on proportion of total fruit yield classed as wastage as determined from nursery records, primarily due to Fusarium rot – 2010

Cropping period	**Deleafing activity**	**% fruit classed as waste by weight (Kg) (with standard errors)**		
		Block 4 Deleafed	**Block 5 Deleafed**	**Block 6 Control**
wk 12 - wk 26	Before first deleaf	0.5 (0.03)	0.4 (0.04)	0.4 (0.03)
wk 27 - wk 37	During deleafing	2.1 (0.06)	0.9 (0.06)	1.7 (0.07)
wk 38 - wk 45	After last deleaf	0.6 (0.05)	0.3 (0.04)	0.3 (0.03)
Throughout season	-	1.2 (0.03)	0.6 (0.03)	0.9 (0.03)

Pest monitoring

On 8 July 2010 (wk 27)

Pest populations were quite small and similar throughout the three blocks. The integrated pest management (IPM) programme had been well managed up to that point and the most important beneficial insects could be found everywhere.

On 29 July 2010 (wk 30)

The lower leaves in block 6 (control) were deteriorating and very little invertebrate activity was found in this part of the canopy. It was concluded that the lower leaves were contributing very little to the overall canopy in terms of providing reservoirs of either pest or beneficial species. If their removal had any impact on pest and beneficial populations then it would be as a result of influencing the environmental conditions in the whole canopy.

The mean numbers of pests and biological control agents per leaf in the upper and middle strata of the crop canopy in blocks 4, 5 and 6 on 29 July 2010 (in week 30) are shown in Table 15. Overall, the numbers of all pest and beneficial species remained similar regardless of the block and the position in the crop canopy.

Table 15. Mean numbers of pests and biological control agents per leaf at two levels in the crop canopy in blocks 4, 5 and 6 on 29 July 2010

Pest species	Associated beneficial species	Block 4 (Deleafed)		Block 5 (Deleafed)		Block 6 (Control)	
		Upper level	Middle level	Upper level	Middle level	Upper level	Middle level
Thrips		0.05	Trace	0.05	Trace	0.02	Trace
	Orius	0.30	0.30	0.50	0.10	0.20	0.10
	Amblyseius	2.00	2.00	4.50	1.00	3.50	1.00
Aphids		Mp 0.05 As 0.05	Mp 0.05 Me 0.05	Mp 0.02	Mp 0.05	Mp 0.02 Me 0.02	Mp 0.06 Me 0.05
	Parasitoids	Trace	Trace	Trace	Trace	Trace	Trace
	Aphidoletes	0	0	0	0	0	0
Spider mites		Trace	Trace	1.00	Trace	0.10	0.10
	Phytoseiulus	Trace	Trace	0.20	Trace	0.01	Trace
	Feltiella	0	0	0	0	0	Trace
Caterpillars		0	0	0	0	0	Ag 0.02
Leafhoppers		0.10	0.10	0	0.05	0	0.10
Leafminers		0	0	0	0	0	Trace

Key: Mp = *Myzus persicae*; Me = *Macrosiphum euphorbiae*; As = *Aulocorthum solani*; Ag = *Autographa gamma*

On 31 August 2010 (wk 35)

The condition of the lower leaves had further deteriorated and there was still very little invertebrate activity. The only significant change over the previous month was the arrival of leafhoppers at the rate of 0.08 per leaf. However, they were also present in similar numbers higher up the canopy.

The mean numbers of pests and biological control agents per leaf in the upper and middle strata of the crop canopy in blocks 4, 5 and 6 on 31 August 2010 (in week 35) are shown in Table 16. In general, the numbers of pest and beneficial species remained similar regardless of the block and the position in the crop canopy. There were two exceptions:

1. Leafhopper were becoming more numerous in block 6 (control), with numbers declining through block 5 and least in block 4 (both deleafed). This was probably due to the direction of invasion from outside habitats rather than an effect of deleafing policy. The trend was kept under observation.
2. Although there were few aphids overall, the formal assessment recorded more *M. persicae* in the tops of the plants in block 4 (deleafed) than in blocks 5 (deleafed) or 6 (control). However, the nursery's own records since the last assessment showed that there had been more spot sprays against *A. solani* in block 6 (control) than in blocks 4 or 5 (both deleafed).

It should be noted that a treatment had been applied against caterpillars since the last assessment but the nursery records indicated that the infestation was similar throughout.

Table 16. Mean numbers of pests and biological control agents per leaf at two levels in the crop canopy in blocks 4, 5 and 6 on 31 August 2010

Pest species	**Associated beneficial species**	**Block 4 (Deleafed)**		**Block 5 (Deleafed)**		**Block 6 (Control)**	
		Upper level	**Middle level**	**Upper level**	**Middle level**	**Upper level**	**Middle level**
Thrips		0	0	0	0	0	0.01
	Orius	0.06	0.02	0.09	0.09	0.01	0
	Amblyseius	3.50	1.00	3.50	1.00	3.50	0.03
Aphids		Mp 0.34	As 0.01	Mp 0.08 As 0.01	Mp 0.09	Mp <0.01 As 0.03	As 0.01
	Parasitoids	0.05	0.01	Trace	Trace	Trace	Trace
	Aphidoletes	0	0	0	0	0	0
Spider mites		0	0	0.01	0	0	0.01
	Phytoseiulus	0	0	Trace	0	0	Trace
	Feltiella	0	0	0	0	0	0
Caterpillars		0	0	0	0	0	0
Leafhoppers		0.03	0	0.09	0.07	0.11	0.08
Leafminers		0	0	0.01	0.03	0.04	0.01

Key: Mp = *Myzus persicae*; Me = *Macrosiphum euphorbiae*; As = *Aulocorthum solani*; Ag = *Autographa gamma*

On 12 October 2010 (wk 41)

The condition of the leaves in the lower half of the canopy had further deteriorated and there was still very little invertebrate activity.

The mean numbers of pests and biological control agents per leaf in the upper and middle strata of the crop canopy in blocks 4, 5 and 6 on 12 October 2010 (in week 41) are shown in Table 17. With the exception of leafminers, which had increased in block 5 (deleafed), numbers of all pests were declining as the end of the season approached. Numbers of biological control agents were similarly declining. Most notably, the Orius population had completely crashed which may have been at least in part due to the scarcity of pollen bearing flowers since the plants were stopped.

Table 17. Mean numbers of pests and biological control agents per leaf at two levels in the crop canopy in blocks 4, 5 and 6 on 12 October 2010

Pest species	Associated beneficial species	Block 4 (Deleafed)		Block 5 (Deleafed)		Block 6 (Control)	
		Upper level	Middle level	Upper level	Middle level	Upper level	Middle level
Thrips		0	0	0	0	0.01	0
	Orius	0	0	0	0	0	0
	Amblyseius	0.05	Trace	0.08	0.05	0.28	0
Aphids		0	0	0	0	0	0
	Parasitoids	0	0	0.02	0	0.02	0
	Aphidoletes	0	0	0	0	0	0
Spider mites		0	0	0.06	0.02	0.03	0.01
	Phytoseiulus	0	0	0	0	Trace	0
	Feltiella	0	0	0	0	0	0
Caterpillars		0	0	0	0	0	0
Leafhoppers		0	0	0.14	0.04	0.01	0.01
Leafminers		0.03	0.03	0.64	0.32	0.08	0.03

In conclusion:

1. There were low levels of pest activity throughout the trial, which was largely due to well managed IPM during the first half of the season.
2. There was very little invertebrate activity in the lower canopy from July onwards, demonstrating that those leaves did not house a reservoir of pest or beneficial species.
3. More spot sprays were applied against *A. solani* in the block which retained lower leaf than in the other two blocks. Although this implied that there was a benefit from deleafing, the effect was not supported by the counts in the main assessments.
4. The formal pest monitoring did not reveal any evidence to suggest that removal of lower leaves had any detrimental effect on IPM.

Economic Appraisal

To ascertain the true benefit to the nursery from deleafing, all the factors need to be considered in financial terms e.g. reduced spray applications, increased labour etc.

The following table is a financial appraisal of deleafing in 2010.

Table 18. Overall economic appraisal for 2010 season

Type	Description	Saving £/m²
Energy	0.88 kWh/m² gas	£0.03
Crop protection	Reduced application of sprays	£0.10
Labour	End of year turnaround	£0.05
Waste removal	1 fewer skip	£0.10
Labour	Removal of leaves	-£0.30
Balance		**-£0.02**

Deleafing will cost the nursery £200 per hectare based on the results of the 2010 season however if some of the other savings as discussed in this report are possible then the following table shows the value of deleafing to the nursery.

Table 19. Overall economic appraisal with increased energy and water savings

Type	Description	Saving £/m²
Energy	12 kWh/m² gas	£0.36
Water	300 litres/m²	£0.52
Crop protection	Reduced application of sprays	£0.10
Labour	End of year turnaround	£0.05
Waste removal	1 fewer skip	£0.10
Labour	Removal of leaves	-£0.30
Balance		**£0.83**

If these savings are possible then the nursery will benefit by £8,300/Ha per annum.

Discussion

There is no adverse effect on plant yield and health from deleafing and savings can be made in energy use. On nurseries where heat destruction for the purposes of maintaining CO_2 levels is not necessary (for example on those where CHP provides the heating) even further energy savings can be realised. Calculated energy savings of 3.4% are likely on nurseries paying close attention to humidity control or 0.25% as a direct result of deleafing.

Water use reduction was not directly measured as a result of deleafing. However this trial has shown that closer attention to detail with regard to irrigation monitoring and management can deliver significant reduction in water consumption.

Although deleafing delivers some benefits and has been proven not to affect plant performance, the cost in this year outweighed the measured benefits. However if the calculated potential savings are realised then the nursery could benefit by £8,300/Ha per annum.

De-leafing creates better humidity conditions within the lower part of the crop. Although no improvement in disease control was recorded, it seems possible that this might be a benefit where the disease pressure is higher.

Further project work is unnecessary because the results achieved this year reflect those in 2009. For nurseries contemplating carrying out deleafing the results presented in this report should be adjusted to reflect individual circumstances and a thorough financial appraisal carried out.

Conclusions

The conclusions of the 2009 report were:

- Removal of lower leaves in pepper plants can be achieved safely without sacrificing yield
- The deleafed area was slightly less humid
- Energy savings of the order 8% were measured during deleafing periods
- No discernible difference in water use was evidenced

The results from this year's work largely bear out the conclusions from the 2009 project. The results provided in this report show that:

- There is no change to yield, crop growth or plant health as a result of deleafing
- There is no change either adverse or beneficial to pest levels or effect on IPM
- Annual energy savings of 0.25%
- Better humidity control could provide further energy savings. Annual energy savings of 3.4% may be possible through improved humidity control
- No reliable difference seen in water use but increased monitoring of water use has resulted in a significant reduction in water consumption of the nursery as a whole

- Financially deleafing was a cost to the nursery but the influence of better humidity control on energy consumption and if the water savings as given by the site water meter are correct then the nursery will save £0.83/m2 or £8,300/Ha.

Technology transfer

May 2010, HDC News, New project announcements

23rd September 2010 - Pepper Technology Group meeting at Abbey View Nurseries

December 2010/January 2011, HDC News technical article - Less leaf means less fuel

Glossary

IPM Integrated Pest Management

RH Relative humidity

HD Humidity deficit

Dose The application of irrigation water usually measured in litres/m2

Drain The run off from irrigation of plants usually measured in litres/m2

Uptake The quantity of irrigation water taken up by the plants and calculated by dose minus drain

References

Adams (2010) Assessing the benefits of deleafing in Peppers, HDC PC285 final report