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Signed on behalf of: Warwick HRI

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The results and conclusions in this report are based on an investigation conducted over one year. The conditions under which the experiment was carried out and the results obtained have been reported with detail and 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.

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GROWER SECTION

Headline

Deleafing in peppers has been shown to save 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 increase in disease.

Background and expected deliverables

Sweet pepper crops are characterised by a large leaf area which increases continuously throughout the growing season. Towards the end of the season the leaf area can be 8 times that of the floor area. However, measurements of leaf photosynthesis in peppers carried out as part of PC 269 showed that lower leaves tended to be unresponsive. Many lower leaves were respiring more than they were photosynthesizing and appeared to be net sinks, rather than sources of assimilates. Hence there might not be a detrimental impact on yield if these leaves were removed.

Although there is interest in deleafing peppers in The Netherlands and Spain, to date there are few published trials. Dueck *et al*. (2006) examined leaf photosynthesis and transpiration at different heights in a sweet pepper canopy. In the period from August through to October it was estimated that the top 12.5% of the canopy was responsible for 89.9% of the photosynthesis but only 34% of the crop transpiration. The bottom 62.5% of the canopy was a net sink (-0.3% of photosynthesis) but predicted to be responsible for 37% of the transpiration.

Leaf removal may be a useful tool for improving water (and fertiliser) use efficiency in sweet peppers. There may also be implications for energy use as less heat will be needed to drive transpiration. However, a balance is required as the transpiration is beneficial for cooling in summer. Deleafing could reduce air humidity slightly which, given that around 20% of energy use in high wire crops is for humidity control, in turn may further reduce energy use.

There may also be advantages from deleafing in terms of reduced disease risk due to lower RH's, and the fact that lower stems should be cleaner and dryer following the removal of old leaf. However, there is also a potential risk that deleafing may increase stem fungal diseases due to the creation of an increased number of wound sites. The two fungi most commonly found causing stem lesions of pepper in the UK are *Fusarium* sp. and *Botrytis cinerea*. It seems unlikely that deleafing will greatly influence the microclimate around flowers and developing fruit, but this cannot be excluded, and if so there may be an effect on Fusarium fruit rot, caused by *Fusarium* species.

Summary of the project and main conclusions

Year 1

Four different deleafing treatments were applied to individual rows (three replicate rows per treatment) of peppers grown within a commercial block of cultivar Special at Valley Grown Nurseries (VGN), Essex. Treatments included a control (no leaf removal), and three levels of deleafing where either 1.6 m (high), 2.0 m (medium) or 2.4 m (low) of leaf was left on the top of each shoot (Figure 1). Deleafing commenced in May, July and August for the high, medium and low deleafing treatments, respectively, and plants were deleafed on a monthly basis thereafter.

Figure 1. *Photograph of a high deleafed row (1.6 m of leaf) taken on 23 September 2008.*

The mean cumulative yield at the end of the season was 21.7 kg/m^2 and there was no significant effect of the deleafing treatments. Similarly there were no significant differences in the total number of flowers and fruits set or fruits cut. Disease monitoring indicated that deleafing pepper cv. Special does not result in production of wound sites on stems that are highly susceptible to *Fusarium* sp. or *B. cinerea*.

To gain a better understanding as to which leaves were working the hardest, we also measured leaf photosynthesis at different heights and light levels. These data were then used to develop a simple model of canopy photosynthesis. Our simulations suggest that the top 40 cm usually accounts for over half of the gross canopy photosynthesis, it is therefore not surprising that leaf areas can be dramatically reduced without reducing yield, supporting the results from the trial.

Year 2

The aim of the experiment in the second year was to deleaf a whole block so that the effects on humidity, energy use, irrigation etc could be quantified. The experiment was carried out at VGN in 2009 on a commercial crop of cv. Cupra grown in blocks 4, 5 and 6. Polythene sheets were used to separate blocks 4 and 5, and blocks 5 and 6. No leaves were removed from blocks 4 and 5, while deleafing was carried out in block 6. Stems were deleafed from the base upwards by picking off leaves to leave 1.6 m (early summer and autumn) to 2 m (mid-summer) of stem with leaves.

Environmental and energy recording

It was slightly cooler (by about 0.2°C) at the top of the canopy in block 6 after deleafing commenced. This may have been due to the fact that less pipe heat was needed for humidity control. However, similar temperature differences occurred in previous years and so it is possible that some of the differences observed as part of this trial may have been due to inherent differences between blocks and slight deviations in sensor calibrations.

The data from independent humidity sensors showed that while the RH at the top of the canopy was initially similar, the RH in block 6 tended to drop below that in block 5 especially after deleafing (by on average 2.1% after the first deleafing). This may have been due to the reduction in transpiration following deleafing. However, examination of the Priva environmental data shows a rather different response in terms of the achieved humidity, with block 6 reading higher than block 5 over the past three years. This difference is probably due to sensor calibration errors (block 5 reading lower than it should have). This may have decreased the energy use associated with humidity control in block 5 and helped to increase the actual humidity above that in block 6.

At times the daytime CO_2 concentrations were greater in block 5 when compared with block 6. However, this was more noticeable early in the year before treatments were applied, and similar differences occurred in previous years. Therefore, this effect was presumably due to block differences (block 5 being closer to the CO_2 inlet), rather than due to the effect of deleafing.

The energy use in block 5 was initially slightly higher than in block 6 and then in February the difference became much greater and more erratic. The energy use then became closer in the spring and summer. In the autumn when block 6 had been deleafed the energy use in block 5 was again higher. The total amount of energy used (from week 2 to 44) was 249 kWh in block 6 with deleafing compared with 261 in block 5. However, only 5.6 kWh of this 11.7 kWh difference occurred after the start of deleafing. This energy saving which was potentially due to deleafing equated to 7 kWh of gas (assuming a boiler and distribution efficiency of 80%) or 2.2% of the annual energy use. The difference between blocks 5 and 6 can be seen in Figure 2. This would suggest that the savings associated with deleafing increased as more leaf was removed, and there was on average an 8.8% saving after the final leaf removal in week 37. Any savings due to deleafing were lost around week 32 due to a problem with RH measurements which increased the humidity control.

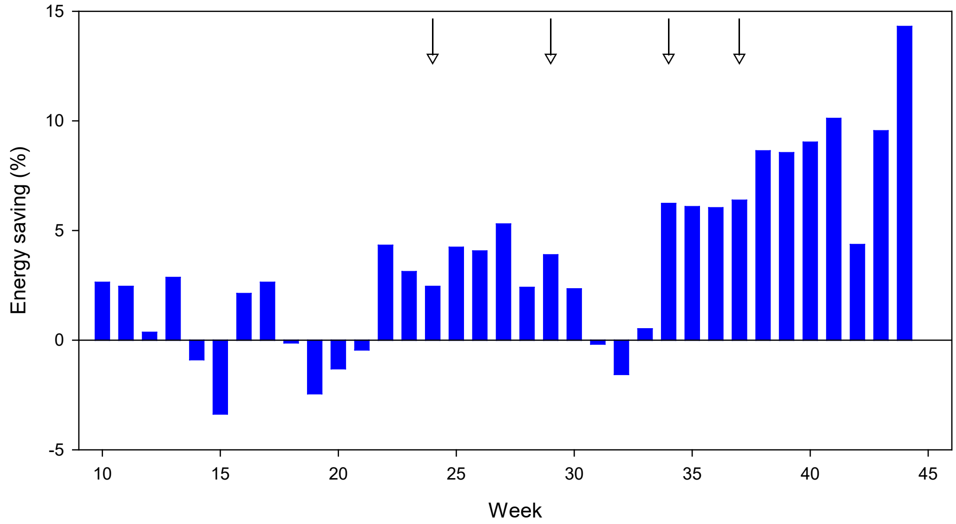

Figure 2*. The reduction in weekly energy use in the deleafed block (CMP 6) in relation to that in block 5 without any correction for inherent differences between compartments. The arrows indicate the times of deleafing in block 6.*

It is very difficult in an unreplicated trial of this type to be certain whether differences are due to treatments or inherent differences between blocks. However, there were some inherent differences between the two blocks in the early part of 2010 with block 6 using less energy than block 5. Also it was clear that the sensor errors had resulted in less humidity control in block 5 which affected the results. When correction factors were included the energy savings from deleafing fell to 4.2 kWh of heat (5.3 kWh of gas) or 1.6% of the annual energy use. The average weekly saving after the final leaf removal (week 37) would be 7.8% and can be seen in Figure 3. This figure is an estimate as the corrections factors cannot be determined with any certainly. Consequently there would be real benefit in repeating the work with the treatments applied in a different compartment.

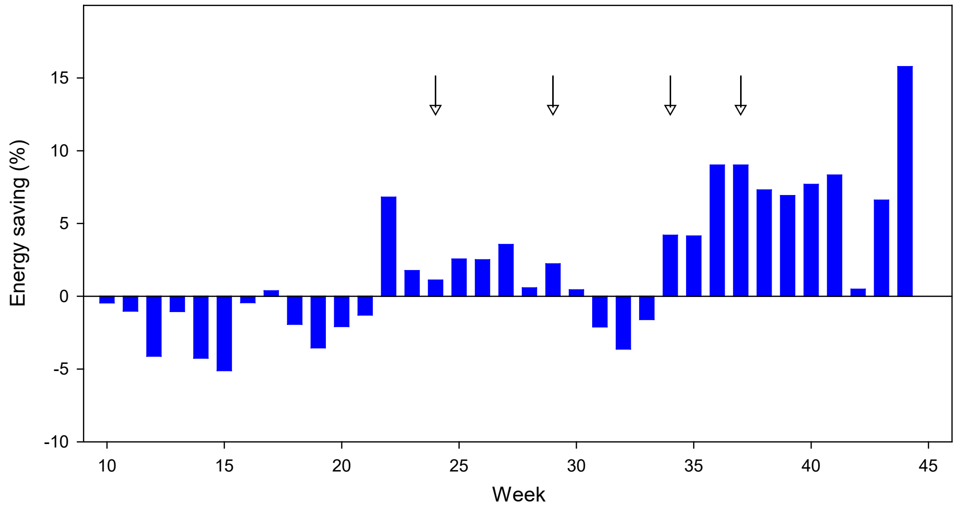

Figure 3. *The reduction in weekly energy use in the deleafed block (CMP 6) in relation to that in block 5 with corrections for inherent differences between compartments and RH control. The arrows indicate the times of deleafing in block 6.*

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. However, this proved to be unreliable as the drainage hole tended to become blocked with debris. Therefore, the drains were checked regularly and the data were examined carefully and unreliable data were deleted. 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 kit in block 5 were smaller than those in block 6. This highlights the need to include more plants in such measurements, and where possible replication of measurements.

Crop and yield recording

There was very little evidence for any significant effect of deleafing on weekly growth or plant height. Furthermore, the crop recording showed that 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.

Analysis of the yields over the past three years shows significant year-to-year variation, but no significant impact of block. Therefore, data from the 2009 trial have been analysed without including any correction factors to take into account intrinsic differences between blocks. There was no true replication of 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 1 fruits in the deleafed and control areas were 28.3 and 28.4 kg/m^2 respectively, the difference was not significant. Similarly the difference in class 2 yields were insignificant with an average of 0.8 and 0.7 kg/m^2 in the control and deleafed areas. Figure 4 shows that there was little evidence for any impact of the treatment on the weekly pattern of yields; there was only one week (week 43) where there was a significant difference in the yield of class one fruits.

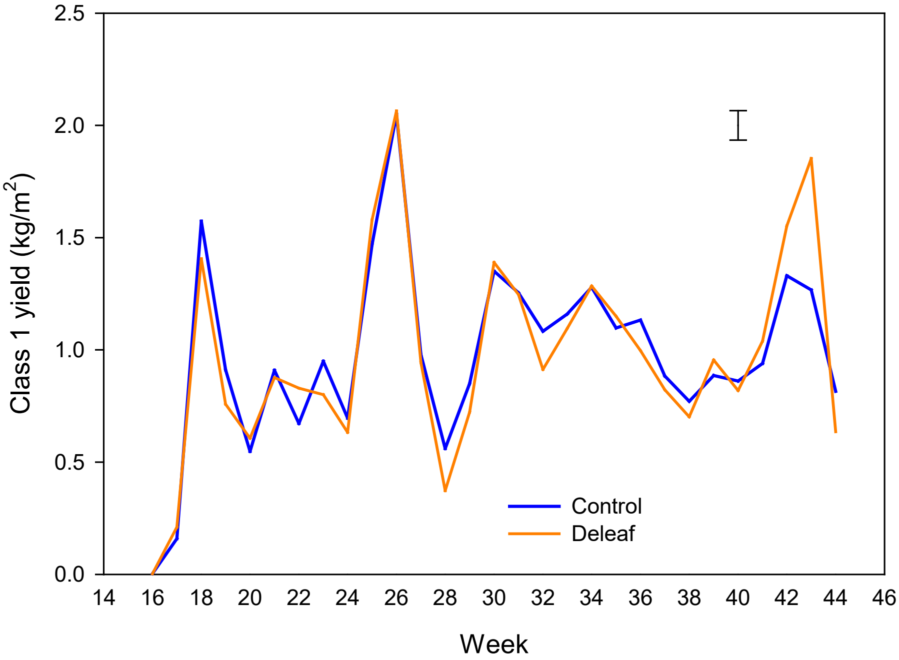

Figure 4*. The weekly yield of class 1 fruits from the deleafed and control areas. The bars represent a pooled standard error of difference for comparing two means in any given week.*

Disease

The effect of partially deleafing pepper stems on occurrence of stem and fruit diseases was examined on sixteen replicate quarter lengths of row in each treatment between June and October. In June and August browning of the stem at positions where fruit stalks had been cut off was evident in both leafed and de-leafed areas of crop; there was no significant difference between treatments. No spreading stem lesions or missing stems were visible at this time. In samples collected from another house where lesions had started to spread from the wound site, a *Fusarium* sp. was consistently isolated. In late September occasional spreading stem lesions and associated plant wilting occurred. Stems with permanently wilted heads were removed by the grower. On 20 October, missing stems or spreading lesions accounted for around 1% of stems in both leafed and deleafed areas of crop. *Botrytis cinerea* was recovered from 10 and *Fusarium* sp. from three out of 14 spreading lesions tested.

Around 100 visibly healthy fruit from each of the leafed and deleafed areas of crop were examined for internal infection by *Fusarium* sp. in October. Fusarium was found in 35% and 38% of fruit from the leafed and deleafed areas respectively, mostly on the seed. These results suggest that deleafing of the lower portion of pepper stems neither increases nor reduces the incidence of Botrytis stem rot or Fusarium internal fruit rot.

Financial benefits

An energy saving of 5.3 kWh/m^2 gas would be worth £901 per ha at current gas prices (1.7 p/kWh). However, gas prices are currently low and are likely to increase in future. If the calculations are carried out based on 2008 prices (2.6 p/kWh) the saving would be £1,378 per ha. In this trial there were three weeks where the savings were lost due to the problems with humidity measurements which would increase this figure. Also the 5.3 kWh/m^2 assumes certain corrections for compartment differences and it is possible that the real savings may be more (or less) than this. The savings would also be greater where more aggressive humidity control is used.

The cost of labour for deleafing will depend on whether additional staff are required. It was estimated that the total additional labour cost at VGN was around £2,500 per ha; the first deleafing was more time consuming, but subsequent deleafing operations were quicker once staff were more experienced and did not need to worry about the petioles where the string was tied at the base of each shoot. This labour cost may in part be offset due to the time required to sweep up leaves that would otherwise drop naturally, and in making it easier to pull out the crop at the end of the season.

Deleafing will produce green waste which will need to be disposed of, but this will be offset by less material to remove at the end of the season. Therefore, the total cost of skips etc should be much the same.

Action points for growers

- It would appear to be safe to deleaf peppers providing that at least 1.6 m of leaf is retained, although it might be beneficial to leave slightly more leaf in summer than at other times of the year.
- Deleafing can reduce energy use by approximately 5 kWh/m^2 of gas, although an alternative approach would be to use the same amount of heat and achieve higher Humidity Deficit’s.

SCIENCE SECTION

Introduction

Sweet pepper crops are characterised by a large leaf area which increases continuously throughout the growing season. Towards the end of the season the leaf area can be 8 times that of the floor area. However, measurements of leaf photosynthesis in peppers carried out as part of PC 269 showed that lower leaves tended to be unresponsive. Many lower leaves were respiring more than they were photosynthesizing and appeared to be net sinks, rather than sources of assimilates. Hence there might not be a detrimental impact on yield if these leaves were removed.

Deleafing is used in tomato crops and Adams *et al.* (2002) found that despite having about 50% of the leaf area, highly deleafed rows (leaving 16 leaves >10cm long) produced the same yield as low deleafing (28 leaves remaining). While Slack (1986) found that leaf removal to the level of two trusses above the ripening truss significantly reduced fruit yields, Cooper *et al*. (1964) showed no significant loss of yield when leaves were removed up to three trusses above the picking truss. Similarly other workers have shown that around 50% of the older leaves can be removed in tomato without any loss in yield (Jones, 1979; Stacey, 1983; Wolk *et al*., 1983). Adams *et al*. (2002) showed that although lower leaves had a reduced photosynthetic capacity, the main reason for the lack of photosynthesis was because the lower leaves of tomato are exposed to small amounts of light. Acock *et al*. (1978) found that the uppermost third of a tomato canopy, which accounted for 23% of the total leaf area, assimilated 66% of the net CO_2 fixed by the canopy. In cucumber it appears that although older leaves do not contribute as photosynthetic organs, they do act as sources of mobile elements that can be exploited by younger, well-lit leaves (Hopkinson, 1966). Consequently, removing these leaves can affect dry matter accumulation. This appears not to be the case in tomato, but there is no data to suggest whether this is the case in sweet peppers.

We are aware that there is some interest in deleafing peppers in The Netherlands and Spain, although there are few published trials. Dueck *et al*. (2006) examined leaf photosynthesis and transpiration at different heights in a sweet pepper canopy. In the period from August through to October it was estimated that the top 12.5% of the canopy was responsible for 89.9% of the photosynthesis but only 34% of the crop transpiration. The bottom 62.5% of the canopy was a net sink (-0.3% of photosynthesis) but responsible for 37% of the transpiration. A study by Bhatt and Srinivasa Rao (1993), where young pepper plants grown in pots were defoliated, suggested that plants had the ability to compensate for defoliation by increasing the photosynthetic efficiency of the remaining leaves. As a result plants with up to 50% defoliation had a higher total dry matter and leaf area at the end of the experiment when compared with the non-defoliated controls. Defoliation caused no significant difference in the fresh and dry weight of fruits. Therefore, clearly there is potential to reduce leaf area in pepper without sacrificing yield.

Despite the fact that lower leaves may not make a positive contribution to net canopy photosynthesis they still transpire. Adams *et al*. (2002) demonstrated that higher deleafing reduced the water uptake of tomatoes. Leaf removal may be a useful tool for improving water (and fertiliser) use efficiency in sweet peppers. There may also be implications for energy use as less heat will be needed to drive transpiration. However, a balance is required as the transpiration is beneficial for cooling in summer. Deleafing could reduce air humidity slightly which, given that around 20% of energy use in high wire crops is for humidity control, in turn may further reduce energy use.

There may also be advantages from deleafing in terms of reduced disease risk due to lower RH's, and the fact that lower stems should be cleaner and dryer following the removal of old leaf. However, there is also a risk that deleafing may increase stem fungal diseases due to the creation of an increased number of wound sites. The two fungi most commonly found causing stem lesions of pepper in the UK are *Fusarium* sp. and *Botrytis cinerea*. It seems unlikely that deleafing will greatly influence the microclimate around flowers and developing fruit, but this cannot be excluded, and if so there may be an effect on Fusarium fruit rot, caused by *Fusarium* species. The objective of this work was to determine the effect of deleafing compared with an untreated control, on stem and fruit disease occurrence in pepper.

In the first year of the project four different deleafing treatments were applied to individual rows (three replicate rows per treatment) of peppers grown within a commercial block of cultivar Special. Treatments included a control (no leaf removal), and three levels of deleafing where either 1.6 m (high), 2.0 m (medium) or 2.4 m (low) of leaf was left on the top of each shoot. The total yield for each row was recorded separately to provide replication for statistical comparison. The mean cumulative yield at the end of the season was 21.7 kg/m^2 and there was no significant effect of the deleafing treatments. Furthermore, there were no significant differences in the total number of flowers and fruits (set and cut), and there was little impact on the weekly patterns. The trial also showed that deleafing did not result in production of wound sites on stems that are highly susceptible to *Fusarium* sp. or *B. cinerea*. Therefore, while even the highest deleafing strategy tested appeared to be safe, the benefits could not be fully quantified. The aim of this experiment was to deleaf a whole block so that the effects on humidity, energy use, irrigation etc could be quantified.

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 2009 grown in blocks 4, 5 and 6. The crop was grown on rockwool slabs and two heads were trained from each plant. Polythene sheets were used to separate blocks 4 and 5, and blocks 5 and 6. No leaves were removed from blocks 4 and 5, while deleafing was carried out in block 6. Based on the results from year 1, the plan was to deleaf leaving 1.6m of leaf at the top of the plant in May/June and then increase this to around 2m of leaf in July and August; this was to increasing the evaporative cooling and leaf area for light interception mid summer. From September the plan was to leave 1.6m of leaf. The timing of deleafing and the approximate height of leaves removed per shoot are shown in table 1.

Table 1.

Week number	Amount of leaf removed (cm)
24	40
29	30
34	20
37	35

Environmental and energy recording and benchmarking

The environmental control in block 4 was via one measuring box located at the top of the canopy. Whereas in blocks 5 and 6 there were two screens at the top of the canopy (one on each side of the path) in each block and the average of the two was used for control. Furthermore, a third measuring box at the bottom of the canopy was added in both blocks 5 and 6. These measurements were checked by independent temperature and RH probes which were calibrated at Warwick HRI prior to their installation. These data were recorded on separate data loggers.

Energy use was recorded on the right hand side of the path in blocks 5 and 6 using heat meters. Also the water uptake in these blocks was measured by installing drain measurement equipment which worked via a tipping spoon which recorded the run-off from 10 plants in both blocks 5 and 6.

Crop and yield recording

The yield (class 1, class 2 and waste) for each crop worker was recorded and analysed separately so as to provide some replication for statistical comparison. Furthermore, nursery staff kept crop records which included weekly growth (stem length), number of flowers, number of fruits set, and the number of fruits cut. There were two separate plots each comprising of 10 shoots in both blocks 5 and 6, and a further plot of 10 shoots in block 4. These data were analysed using ANOVA where the blocking was by plot.

Plant heights were also recorded monthly by staff from Warwick HRI. On each occasion the height (from the top of the block to the head of the plant) of 40 shoots in the control area (20 in block 4, and 20 in block 5) and 40 shoots in the deleafed area (block 6) were recorded. The forty shoots were spread equally been the left and right hand sides of the central path as plots of five adjacent shoots. Furthermore, in block 6, the length of stem with leaf was also measured. These data were analysed using ANOVA where the blocking was by plot.

Disease monitoring

The crop was examined for disease on 3 June, before the start of deleafing, and again on 27 August (with some deleafing) and 20 October 2009 (after the completion of deleafing). Rows were walked and each head was examined for stem disease, from the stem base to around 2m high, from one pathway. The number of stem wound sites with partial or complete browning across the wound surface, the number of spreading lesions, and the number of missing plants were counted. Stem wound sites occurred where fruit had been cut off, usually flush to the stem. There was no obvious large wound sites at the points where leaves had been picked off.

At the final visit, 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. It was reported by nursery staff that Fusarium external or internal fruit rot was the major cause of fruit wastage, though some would have been due to mis-shapes or blossom end rot.

Experiment design and analysis

There were two treatments (leafed and deleafed stem) each with 16 replicate plots. Individual plots consisted of one quarter length of a row comprising 48 plants and 96 heads (stems). Four complete row lengths were monitored in the leafed crop area (one each in bays 4 and 6 in block 4; one each in bays 12 and 14 in block 5) and four in the leafed area (one each in bays 18, 20, 22 and 24 in block 6). These rows were selected to give a distribution throughout the leafed and deleafed crop areas, and so that two rows were under glasshouse gutters and two under ridges in each area.

It was not possible to randomise replicates as there was only one area of each treatment. Results were examined by ANOVA on the assumption that there were no inherent differences in the glasshouse environment, or other factor, that might influence occurrence of stem and fruit diseases, except for the deleafing treatment. The effect of deleafing treatment and row position were examined in a factorial analysis.

A sample of 17 stem wound sites with complete browning were collected on 3 June, and 14 spreading stem lesions on 20 October, and tested for fungal pathogens in the laboratory. Tissues were surface disinfected in sodium hypochlorite (1% for 3 mins), rinsed in sterile distilled water, and plated onto potato dextrose agar (PDA). Fungal species growing out of tissues were identified by colony appearance and spore morphology.

Results

Environments and benchmarking

Outside environmental conditions

The external air temperatures and solar radiation for the 2009 season are shown in Figure 1.

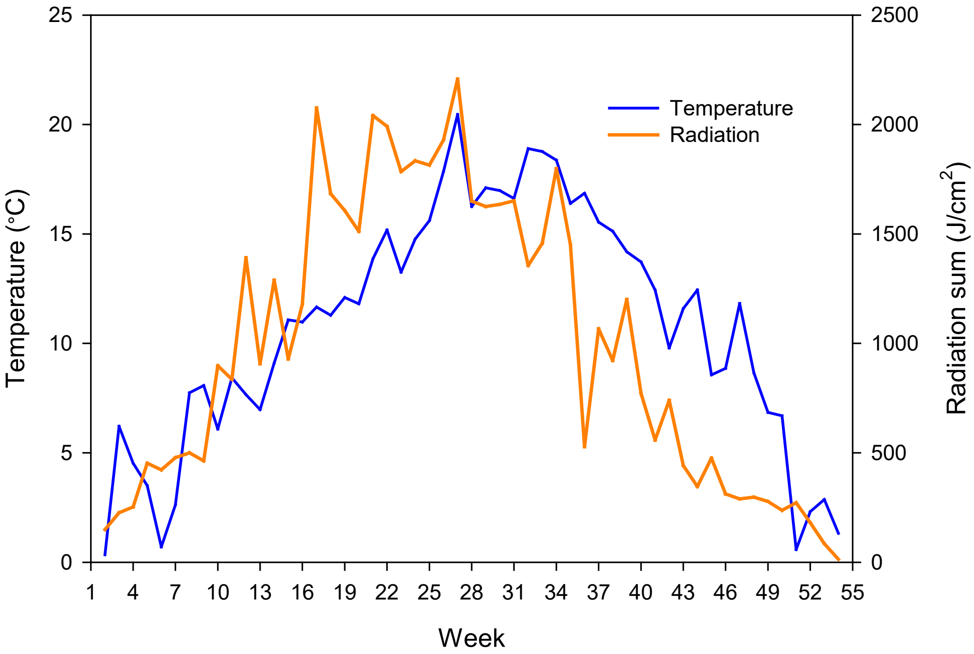

Figure 1. *The average weekly external air temperature and external solar radiation for 2009.*

Temperatures

Data from independent temperature sensors positioned in each measuring box indicate that it was slightly cooler (by about 0.2°C) at the top of the canopy in block 6 after deleafing commenced (Figure 2 top). This may have been due to the fact that less pipe heat was needed for humidity control. At the bottom of the canopy (Figure 2 bottom) the difference between blocks was less pronounced possibly because the leaf removal meant less evaporative cooling in this lower region, which may have counteracted the effects of any difference in the minimum pipe.

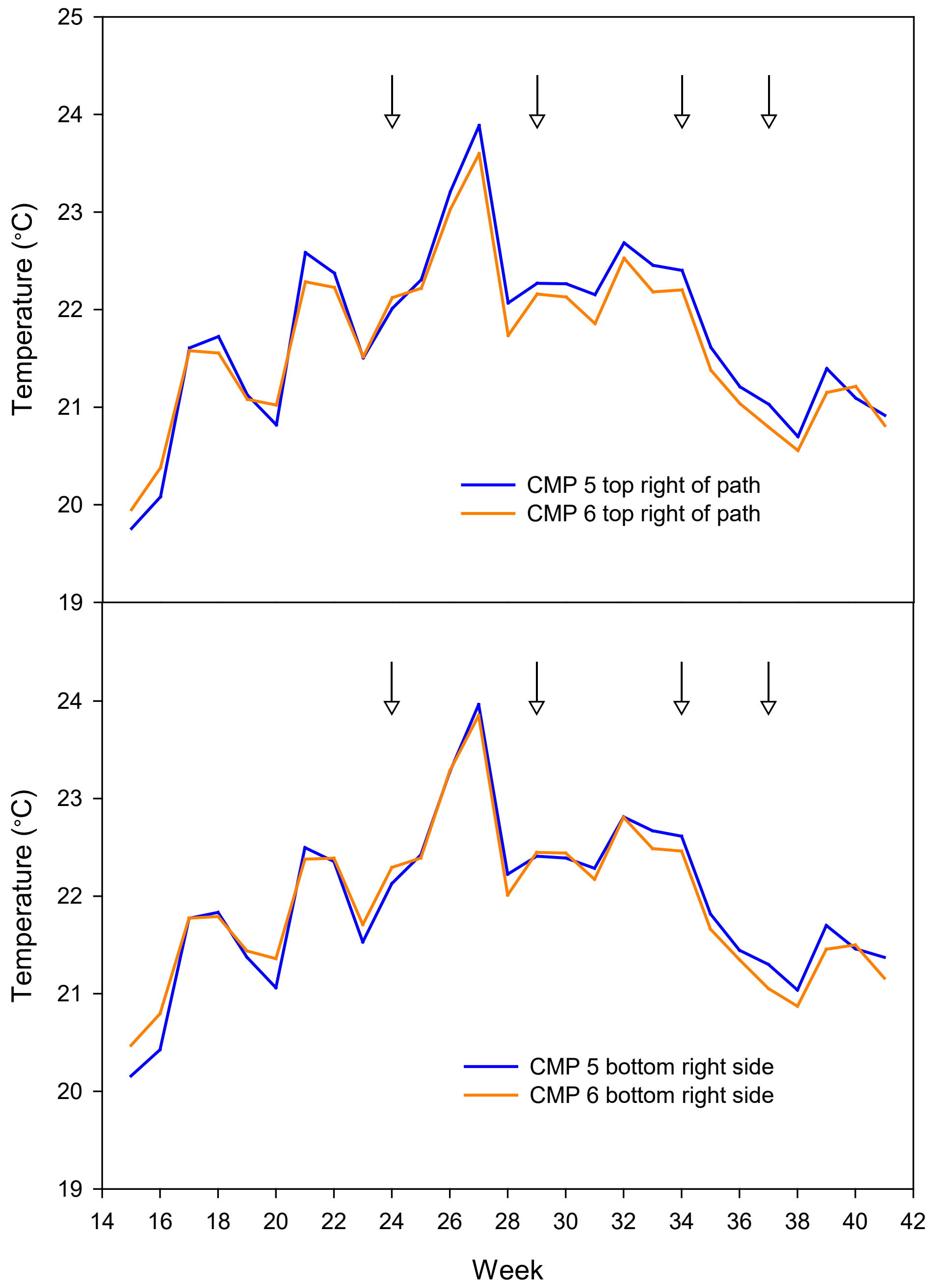

Figure 2. *The average weekly air temperatures on the right hand side of the path in compartment 5 with no deleafing, and compartment 6 which was deleafed, recorded using independent temperature sensors. The arrows indicate the weeks in which deleafing took place. The top graph shows temperatures at the top of the canopy and the bottom graph shows the temperatures at the bottom of the canopy.*

While these independent sensors were calibrated prior to use and should be relatively accurate, the differences might be due to small differences in the relative position of the measuring boxes, the accuracy of sensors used for climate control, or inherent differences between blocks. This was investigated by comparing the output of the temperature sensors, and investigating differences over recent years. The Priva temperature data for 2009 (Figure 3 top) also suggests that it may have been slightly cooler in block 6. The differences on the right hand side of the path were larger (around 0.4 °C from the start of deleafing) than those from the independent sensors (0.2°C) due to the fact that in block 5 the Priva sensors tended to read slightly above those from the independent sensors.

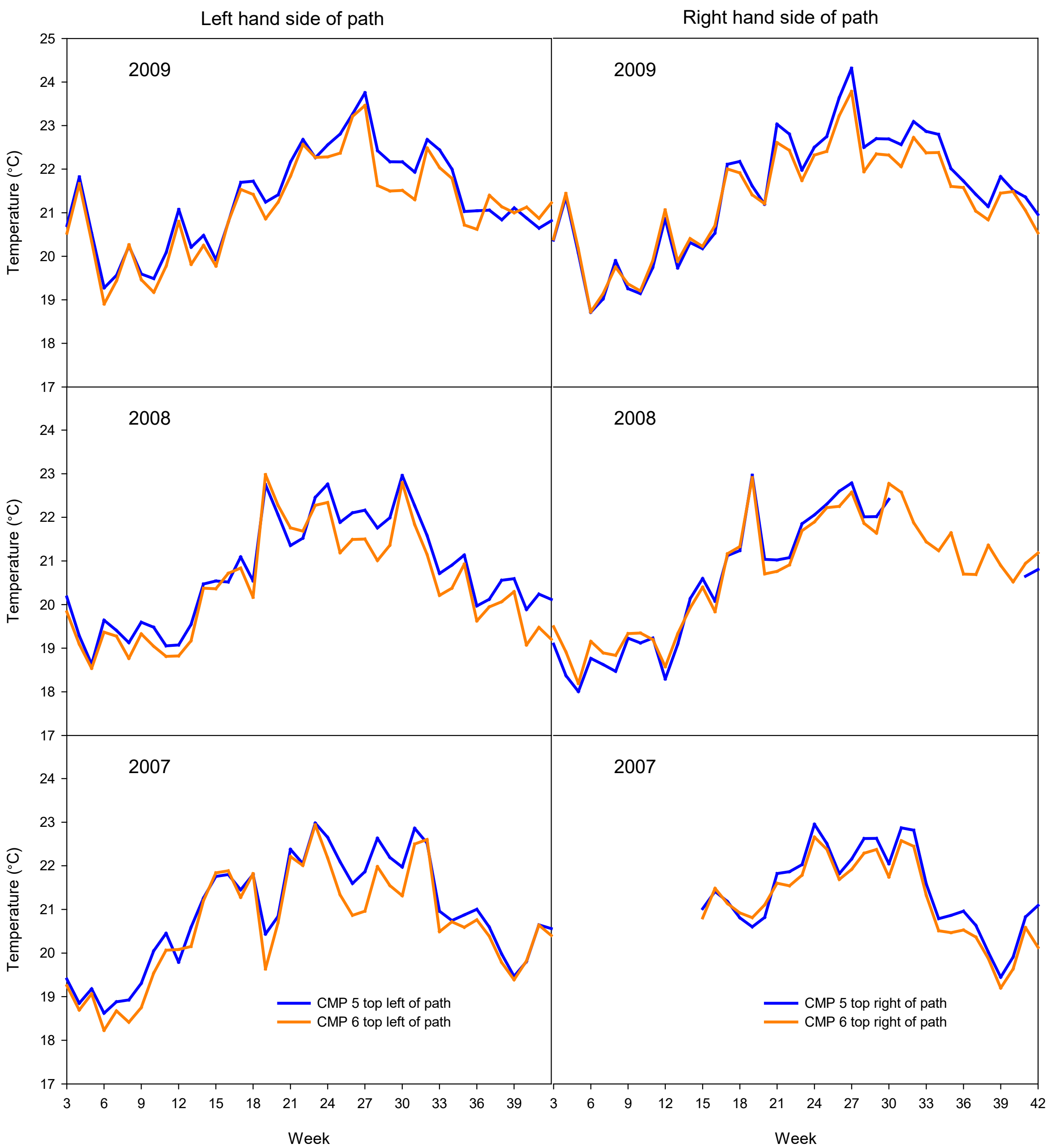

Figure 3. *The average weekly air temperatures recorded by the Priva climate control computer on the left and right hand side of the central path in compartments 5 and 6. In 2009 compartment 5 was not deleafed, while leaves were removed in compartment 6.*

The differences between compartments are not limited to 2009. In 2007 a summer shading experiment was carried out in blocks 5 and 6 (HDC project PC 269) and so some of the differences in this year may have been associated with the shading treatments. However, in 2008 there were no treatments applied to blocks 5 and 6 and yet there are still some temperature differences between these compartments (especially on the left hand side). Consequently, it is possible that some of the differences observed as part of this trial may have been due to inherent differences between blocks and slight deviations in sensor calibrations.

Humidity

The data from the independent humidity sensors (Figure 4) showed that while the RH at the top of the canopy on the right hand side was initially similar, the RH in block 6 tended to drop below that in block 5 especially after deleafing (by on average 2.1% after the first deleafing). This may have been due to the reduction in transpiration following deleafing.

The RH at the bottom of the canopy was on average 2.4% lower than that at the top of the canopy. Furthermore, the RH at the bottom of the canopy was lower in block 6 when compared with that in block 5 (on average by 2.3% after the start of deleafing). However, this difference was also seen before deleafing commenced, and so it is questionable how much of this effect may be due to the treatment.

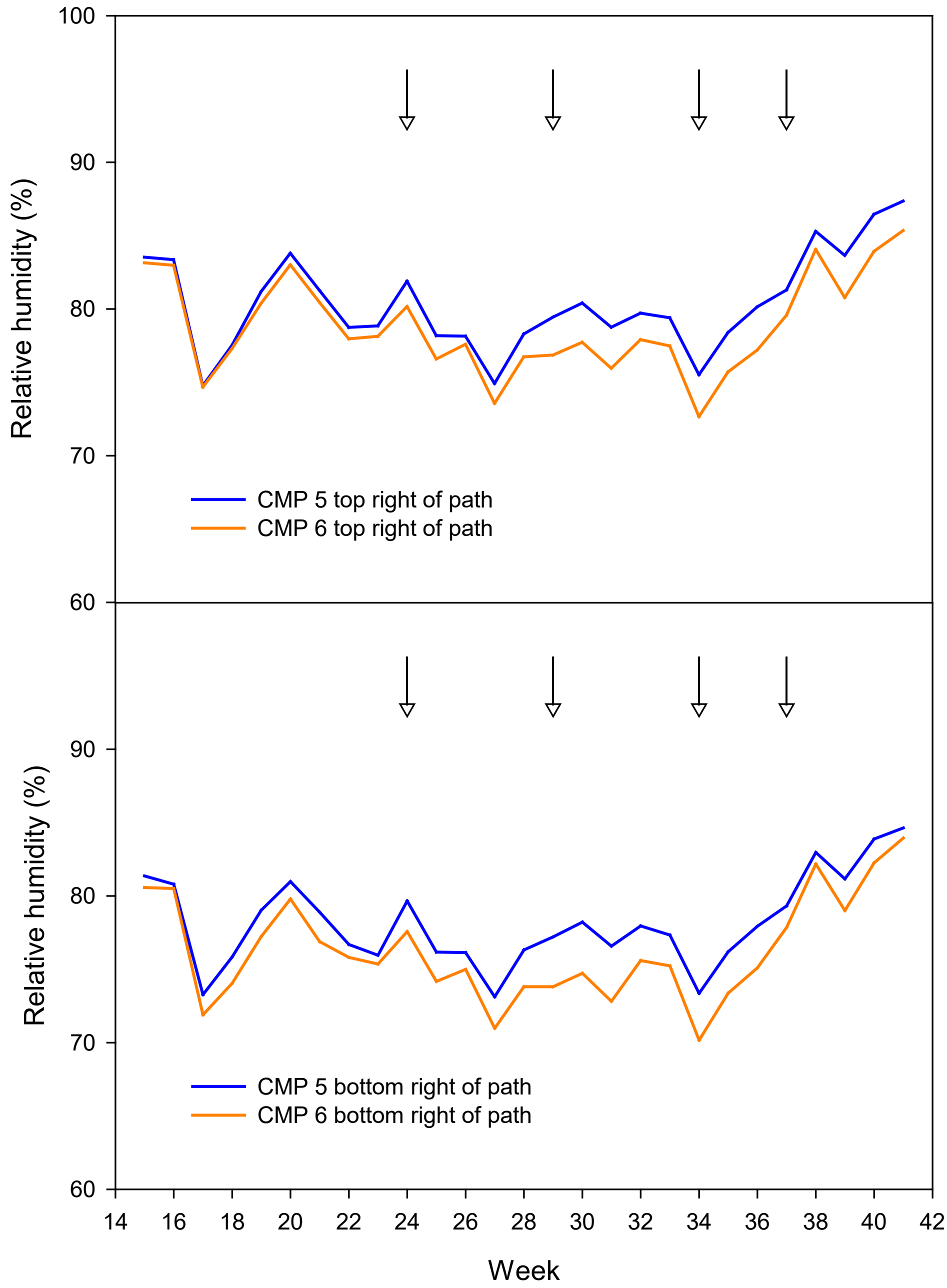

Figure 4. *The average weekly relative humidity on the right hand side of the path in compartment 5 with no deleafing, and compartment 6 which was deleafed, recorded using independent RH sensors. The arrows indicate the weeks in which deleafing took place. The top graph shows the humidity at the top of the canopy and the bottom graph shows the humidity at the bottom of the canopy.*

Examination of the Priva environmental data (Figure 5) shows a rather different response in terms of the achieved humidity. While the humidity of the left hand side looked broadly similar in both blocks, the humidity on the right hand side in block 6 appears to have been higher than in block 5 over the past three years. This difference is probably due to sensor calibration errors. At the top, on the right hand side of block 6 the Priva was around 1.2% RH higher than the independent rotronics sensors, while it was 2.7% RH lower in block 5.

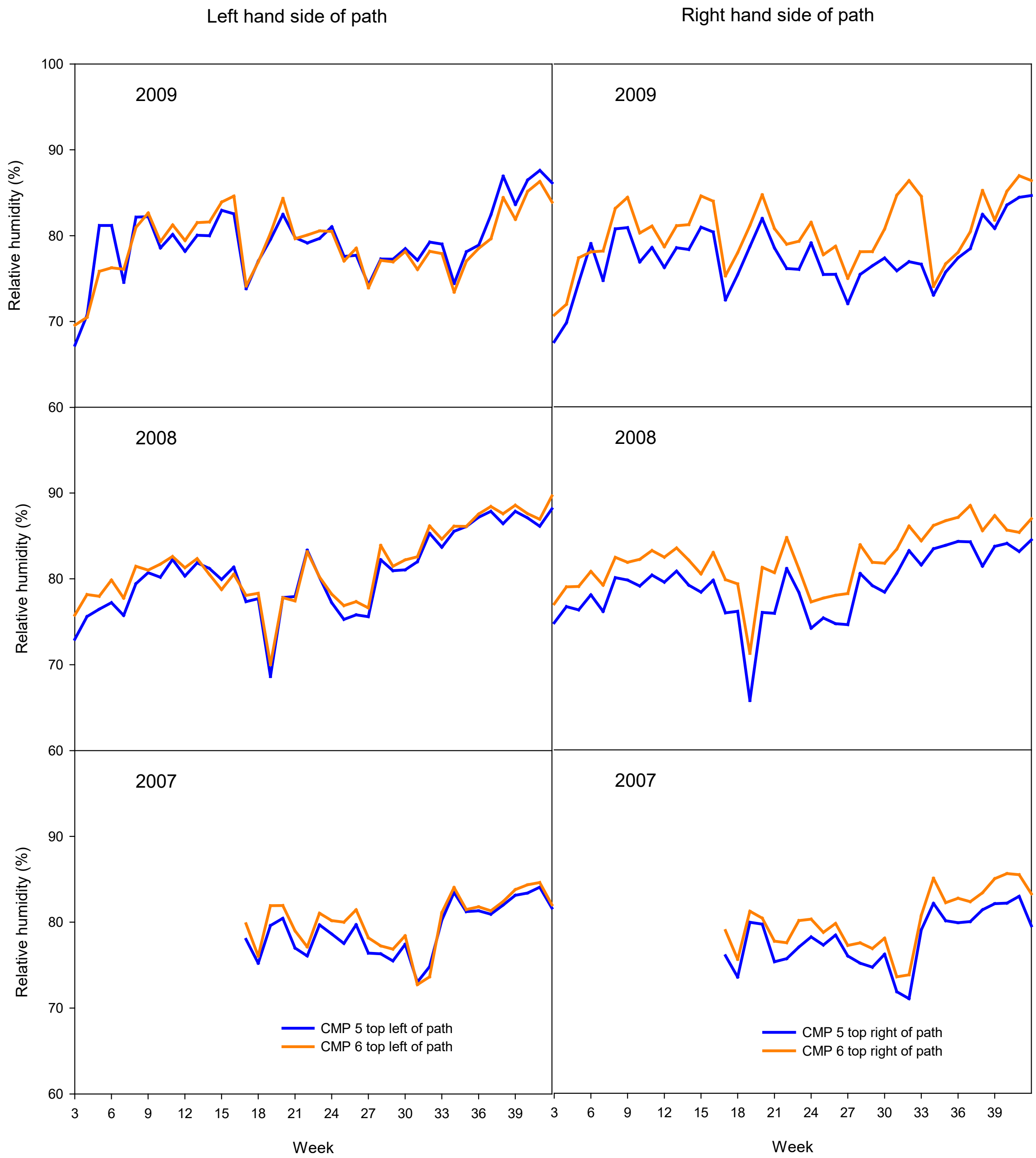

Figure 5. *The average weekly relative humidity recorded by the Priva climate control computer on the left and right hand side of the central path in compartments 5 and 6. In 2009 compartment 5 was not deleafed, while leaves were removed in compartment 6.*

In April the measuring boxes were checked by assessing what temperature the sensors read when the wick was removed from the wet bead (and so should have read the same as the dry bead). The sensors at the top right hand side of block 5 showed a 0.3°C difference, which could account for around a 2.5% difference in RH. As a result the wet temperature bead in block 5 was changed in May, but clearly this did not rectify the situation.

The fact that the Priva was reading a slightly high RH in block 6 on the right hand side, may have increased the energy use associated with humidity control and decreased the actual humidity below that in block 5.

Carbon dioxide concentration

At times the daytime CO_2 concentrations were greater in block 5 when compared with block 6 (Figure 6). However, this was more noticeable early in the year before treatments were applied, and similar differences occurred in previous years. Therefore, this effect was presumably due to block differences (block 5 being closer to the CO_2 inlet), rather than due to the effect of deleafing.

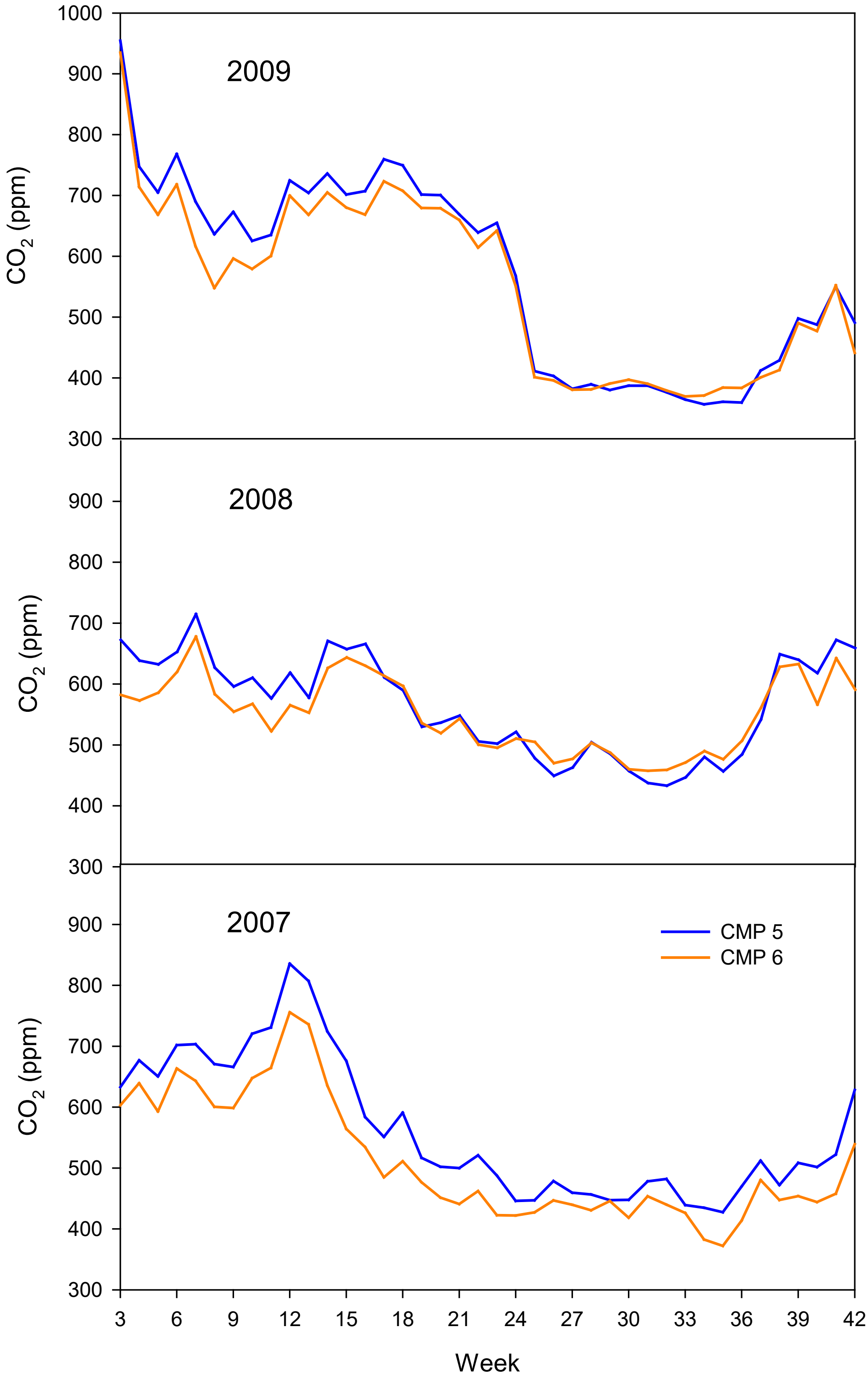

Figure 6. *The average weekly CO_2 concentrations recorded by the Priva climate control computer in compartments 5 and 6. In 2009 compartment 5 was not deleafed, while leaves were removed in compartment 6.*

Energy use

The daily energy use data for blocks 5 and 6 can be seen in Figure 7. The energy use in block 5 was initially slightly higher than in block 6, and then in February the difference became much greater and more erratic. The energy use then became closer in the spring and summer. In the autumn when block 6 had been deleafed the energy use in block 5 was again higher. The total amount of energy used (from week 2 to 44) was 249 kWh/m^2 in block 6 with deleafing, compared with 261 in block 5. However, only 5.6 kWh/m^2 of this 11.7 kWh/m^2 difference occurred after the start of deleafing. This energy saving which was potentially due to deleafing equated to 7 kWh/m^2 of gas (assuming a boiler and distribution efficiency of 80%) or 2.2% of the annual energy use. The difference between blocks 5 and 6 can be seen more clearly in Figure 8. This would suggest that the savings associated deleafing increased as more leaf was removed, and there was on average an 8.8% saving after the final leaf removal in week 37.

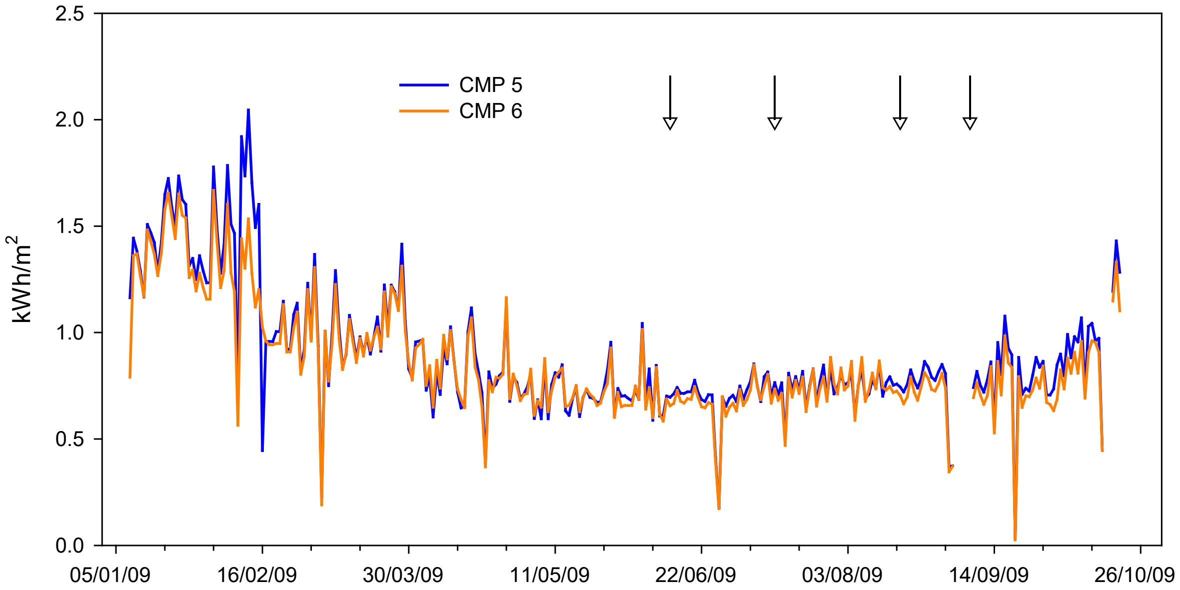

***Figure 7**. Pattern of daily energy in blocks 5 and 6. The arrows indicate the times of deleafing in block 6.*

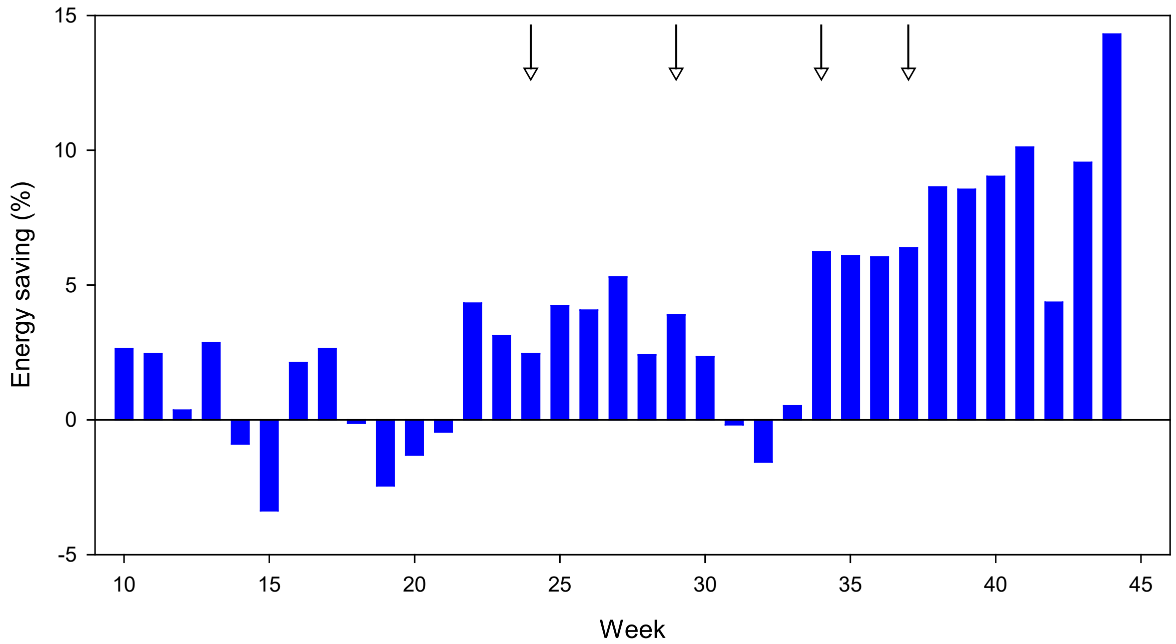

Figure 8. *The reduction in weekly energy use in the deleafed block (CMP 6) in relation to that in block 5 without any correction for inherent differences between compartments. The arrows indicate the times of deleafing in block 6.*

The difference between blocks 5 and 6 in January and February 2009 was a concern as there were no treatment differences between the two blocks at this time. However, the fact that the difference was not consistent meant it was hard to draw any conclusions or to benchmark the energy of one compartment against that of the other. Therefore, data from the early part of 2010 was used instead. During the early part of 2010 (weeks 1 to 6) when heat was being applied to increase the glasshouse temperature, the energy use in block 5 was 7.5% higher than in block 6. Therefore, the 2009 data was corrected by increasing the energy use in block 6 by 7.5% whenever the glasshouse was being heated (i.e. not at a minimum pipe). Figure 9 top shows the corrected energy savings. When this correction is applied the deleafing savings from week 24 become 4.8 kWh/m^2 of heat (6 kWh/m^2 of gas) or 1.8% of the annual energy use. The average weekly saving after the final leaf removal (week 37) would be 7.1%.

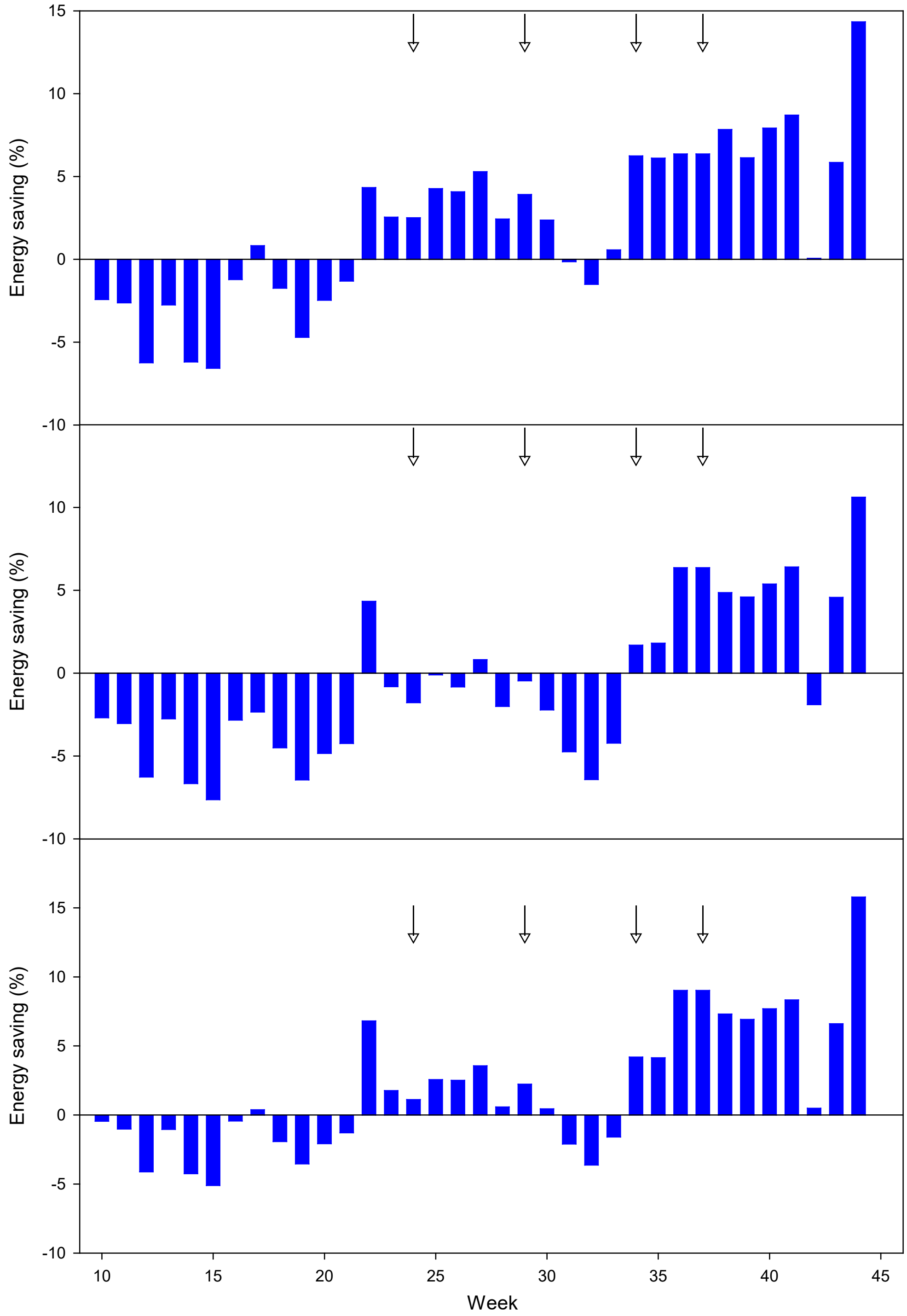

Figure 9. *The reduction in weekly energy use in the deleafed block (CMP 6) in relation to that in block 5 once corrected for inherent differences between compartments. In the top figure block 6 is increased by 7.5% when heating to raise the glasshouse temperature. In the middle figure block 6 is increased by 7.5% when heating and 5% when at minimum pipe. In the bottom figure the 7.5% and 5% correction are used, together with a 0.14 kWh/m²/week increase in block 5 to take into account differences in humidity control. The arrows indicate the times of deleafing in block 6.*

Up until week 21 block 6 appeared to use more energy than block 5. This suggests that the 7.5% correction may be a slight overestimate during this period which could well be the case as the differences between compartments may well be affected by the external conditions (outside temperature, wind speed and direction). However, this is impossible to quantify in an unreplicated experiment of this type. Furthermore, the data in Figure 9 top does not have a correction applied when the glasshouse is running at the minimum pipe, although it is possible that due to differences in flow rates there may have been some differences in the heat applied between the two blocks when running a minimum pipe. The fact that there are small energy saving in weeks 22 and 23, before leaves were removed, suggests that this might be the case, however, again this is difficult to quantify with any certainty. If a 5% correction is applied for the time when at minimum pipe (estimated based on a relationship between pipe temperature and the amount of heat delivered) the energy savings would drop to 1.4 kWh/m^2 of heat (1.8 kWh/m^2 of gas) or 0.5% of the annual figure (Figure 9 middle).

The energy saving in block 6 appears to be reduced for weeks 31 to 33. This coincides with high RH values recorded in this block on the Priva (Figure 5, top right); the measuring box on the right hand side read 10% higher. Given that the climate control computer uses the average of the readings from the left and right hand sides, the average RH in block 6 would have been about 5% higher than in block 5. The net result of this appeared to be a 5% increase in energy use, or to express it another way 0.34 kWh/m^2/week more than a few weeks earlier relative to block 5. Throughout much of the experiment the Priva tended to read low on the right hand side of block 5, when compared with block 6 or the independent temperature sensors. Consequently less energy would have been used in the block for humidity control. Based on what happened in weeks 31 to 33, this could mean that the energy saving would be around 2% higher (equivalent to 0.14 kWh/m^2/week). If the energy use in compartment 5 is increased by 0.14 kWh/m^2/week as a crude way of adjusting for the errors in RH the energy savings from deleafing would increase to 4.2 kWh of heat (5.3 kWh/m^2 of gas) or 1.6% of the annual energy use. The average weekly saving after the final leaf removal (week 37) would be 7.8% and can be seen in Figure 9 bottom. The energy use and associated corrections are summarised in table 2.

***Table 2**. Summary of the energy savings associated with deleafing and the associated corrections to take into account differences between blocks.*

Correction to energy data	Energy saving			
	Heat saved from wk 37 (kWh/m^2)	Gas saved from wk 37 (kWh/m^2)	Avg % saving per wk after last deleafing	% saving of annual energy use
Raw data	5.6	7.0	8.8	2.2
CMP 6 increased by 7.5% when heating	4.8	6.0	7.1	1.8
CMP 6 also increased by 5% at min pipe	1.4	1.8	5.1	0.5
CMP 5 also increased by 0.14 $kWh/m^2/wk$ due to differences in humidity control	4.2	5.3	7.8	1.6

Water use

The amount of irrigation applied (dose) was downloaded from the Priva based on the duration of each irrigation round. A tipping spoon system was used to measure drainage for 10 plants in each block. However, this proved to be unreliable as the drainage hole tended to block with debris. Therefore, the drains were checked regularly and the data were examined carefully and unreliable data were deleted. The uptake (primarily transpiration) was calculated as the irrigation applied minus the drain (Figure 10).

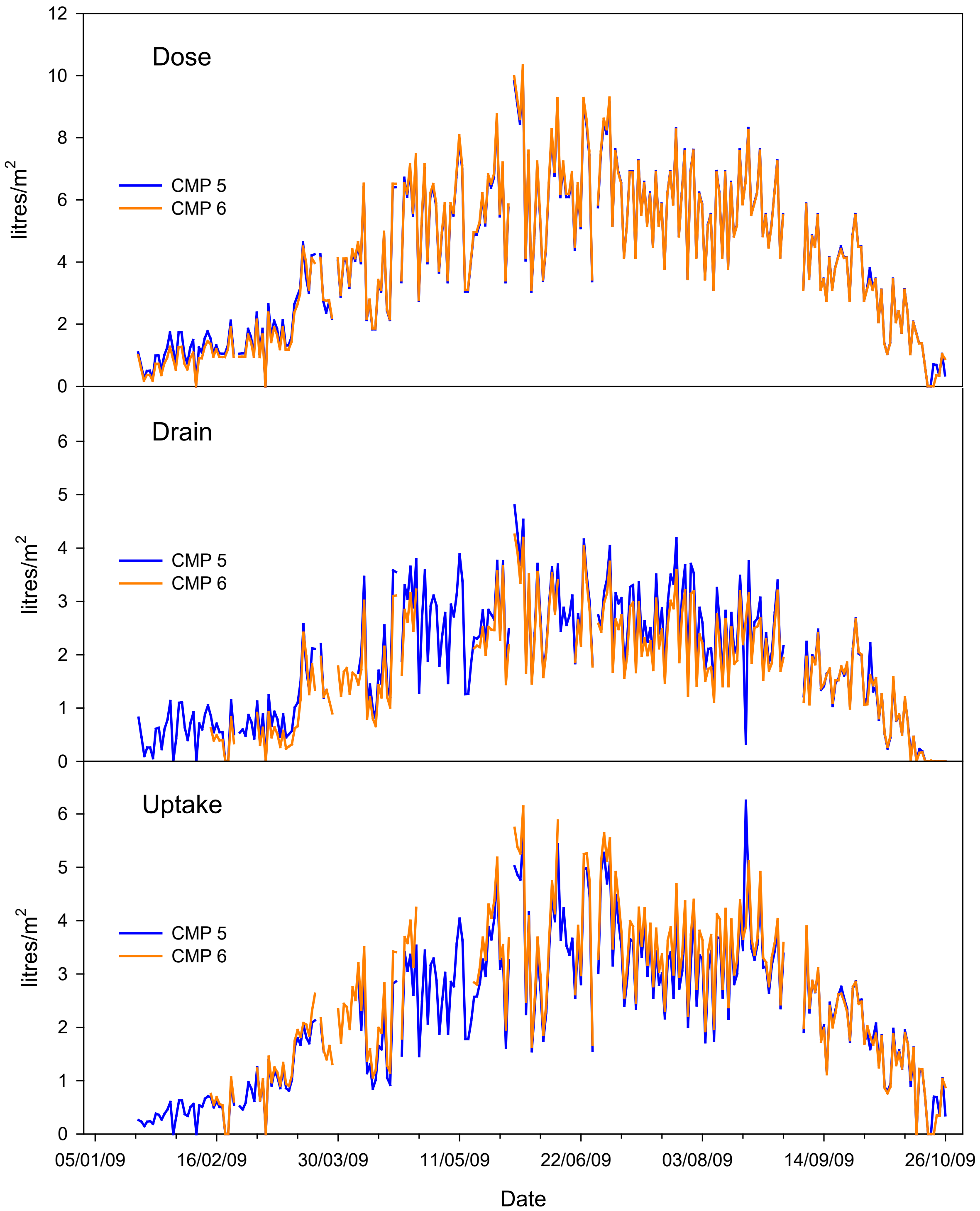

Figure 10. *Comparison of the amount of irrigation dosed in each compartment and the amount of run off as measured with a tipping spoon system. The uptake is calculated as the dose minus drain. Periods when the drain (and therefore uptake) data appeared inaccurate have been deleted.*

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. In fact that uptake in block 6 was predicted to be greater than that for block 5 on several occasions, especially in the spring and summer before appreciable amounts of leaf were removed. The reason for reduced uptake (increased drain) in block 5 was investigated. The most likely explanation appeared to be because the plants on the drain kit in block 5 were smaller than those in block 6; the plants on the drain kit in block 5 were 20 cm shorter than those in block 6. This highlights the need to include more plants in such measurements, and where possible replication of measurements.

<u>Crop and yield recording</u>

Crop recording data

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 11)). This was supported by the crop heights recorded every month by staff from Warwick HRI; there was no significant difference ($P > 0.05$) in the height of the control and deleafed plants on any of the occasions when plants were measured. The plant heights for the control block can be seen in Figure 12 as can the length of stem with leaves in the deleafed block. These measurements are from the growing point to the end of the lowest leaf.

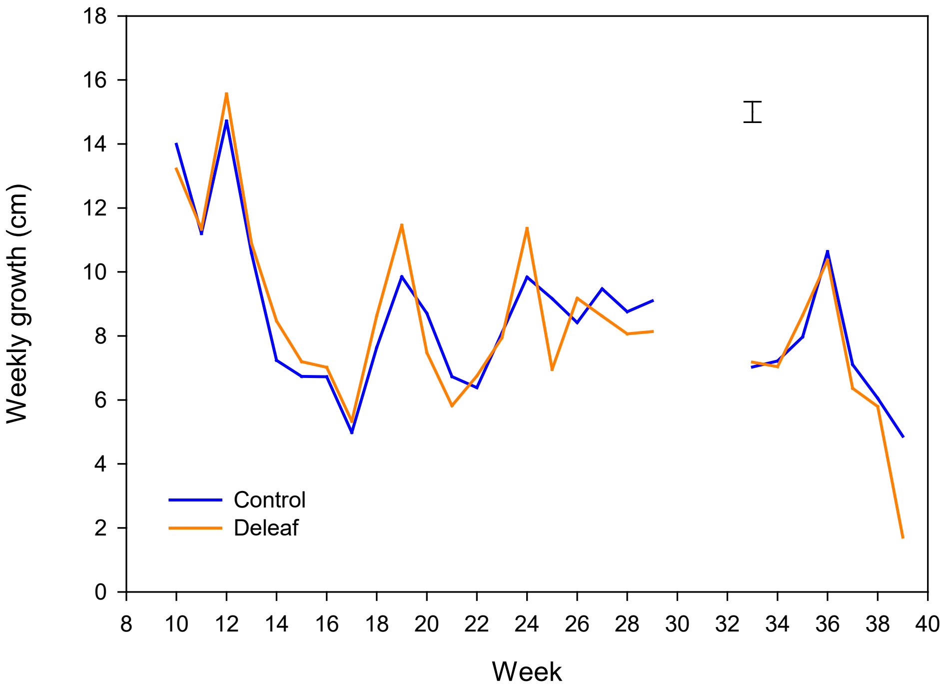

Figure 11. *The average growth per week for 20 shoots per treatment. The bar represents a pooled standard error of difference for comparing two means in any given week.*

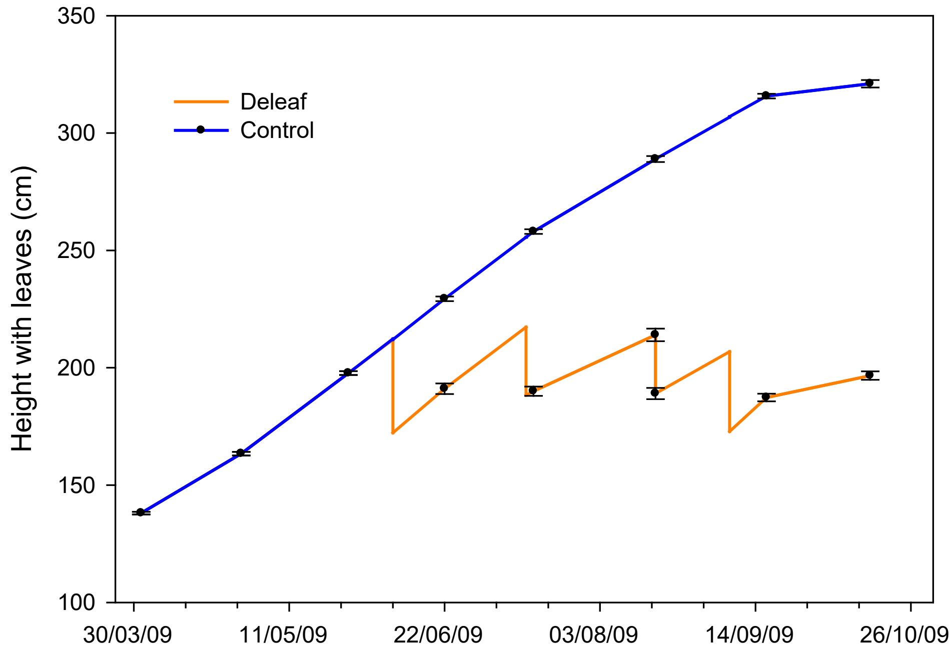

Figure 12. *Increase in plant height over time and the amount of the stem with leaves in the deleafed area (block 6). The points represent the mean of measured values and the error bars show the SEM.*

The crop recording showed that deleafing did not have a significant impact ($P > 0.05$) 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 (Figure 13).

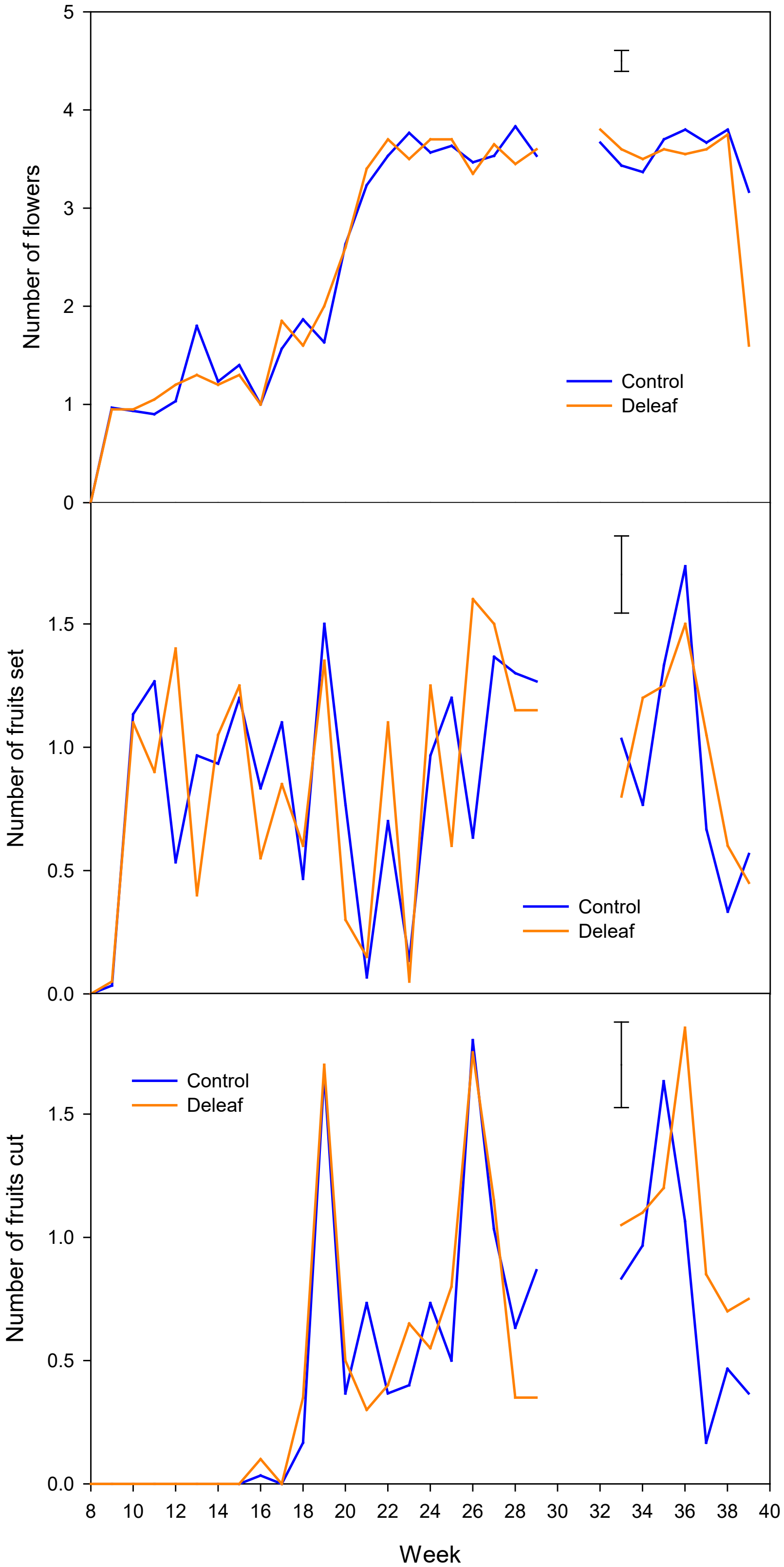

Figure 13. *The number of flowers, fruits set and fruits cut per week. Data are the average for 20 shoots per treatment and the bars represent a pooled standard error of difference for comparing two means in any given week.*

Yields

Analysis of the yields over the past three years (Figure 14) shows significant ($P < 0.05$) year-to-year variation, but no significant impact of block ($P > 0.05$). Therefore, data from the 2009 trial have been analysed without including any correction factors to take into account intrinsic differences between blocks. Note that a summer shading experiment was carried out in 2007 (HDC project PC 269) and it is possible that the treatments may have had a small impact on yield; blocks 4 and 5 were shaded while block 6 was unshaded.

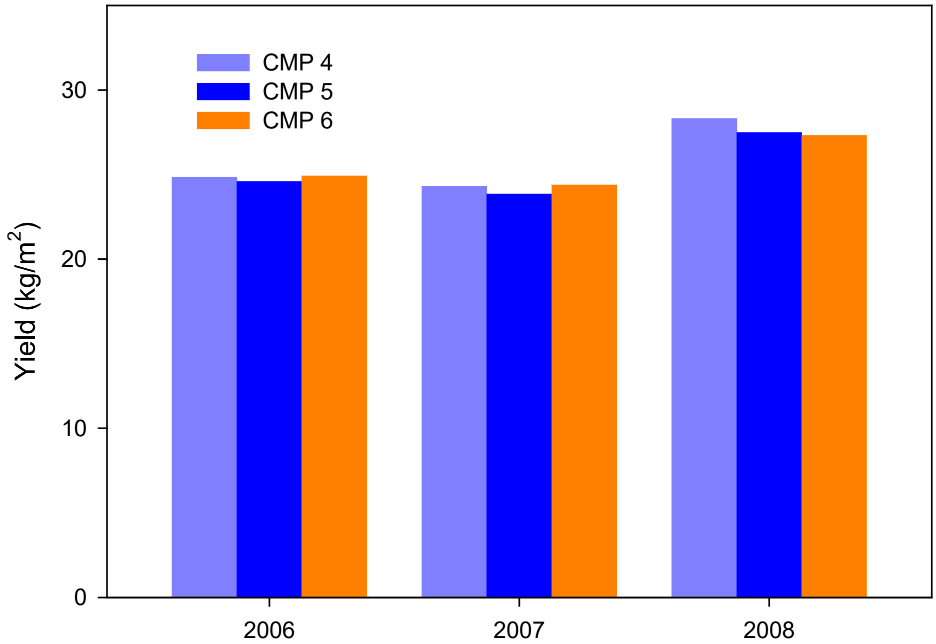

Figure 14. *Cumulative yields for blocks 4, 5 and 6 for the three years before the deleafing trial.*

In 2009 there were five crop workers in blocks 4, 5 and 6, including two workers who were assigned to work in more than one block. The yield from the worker who covered blocks 5 and 6 was split accordingly, with the Monday's picks assigned to block 5 and the remaining picks to block 6. The weekly yields are shown in Figure 14, divided by class 1 and class 2 (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 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 1 fruits in the deleafed and control areas were 28.3 and 28.4 kg/m^2 and the difference was not significant. Similarly the difference in class 2 yields were insignificant ($P > 0.05$) with an average of 0.8 and 0.7 kg/m^2 in the control and deleafed areas respectively. Figure 15 shows that there was little evidence for any impact of the treatment on the weekly pattern of yields; there was only one week (week 43) where there was a significant difference ($P < 0.05$) in the yield of class one fruits, and two weeks (weeks 20 and 35) where there was a significant difference ($P < 0.05$) for class 2 fruits.

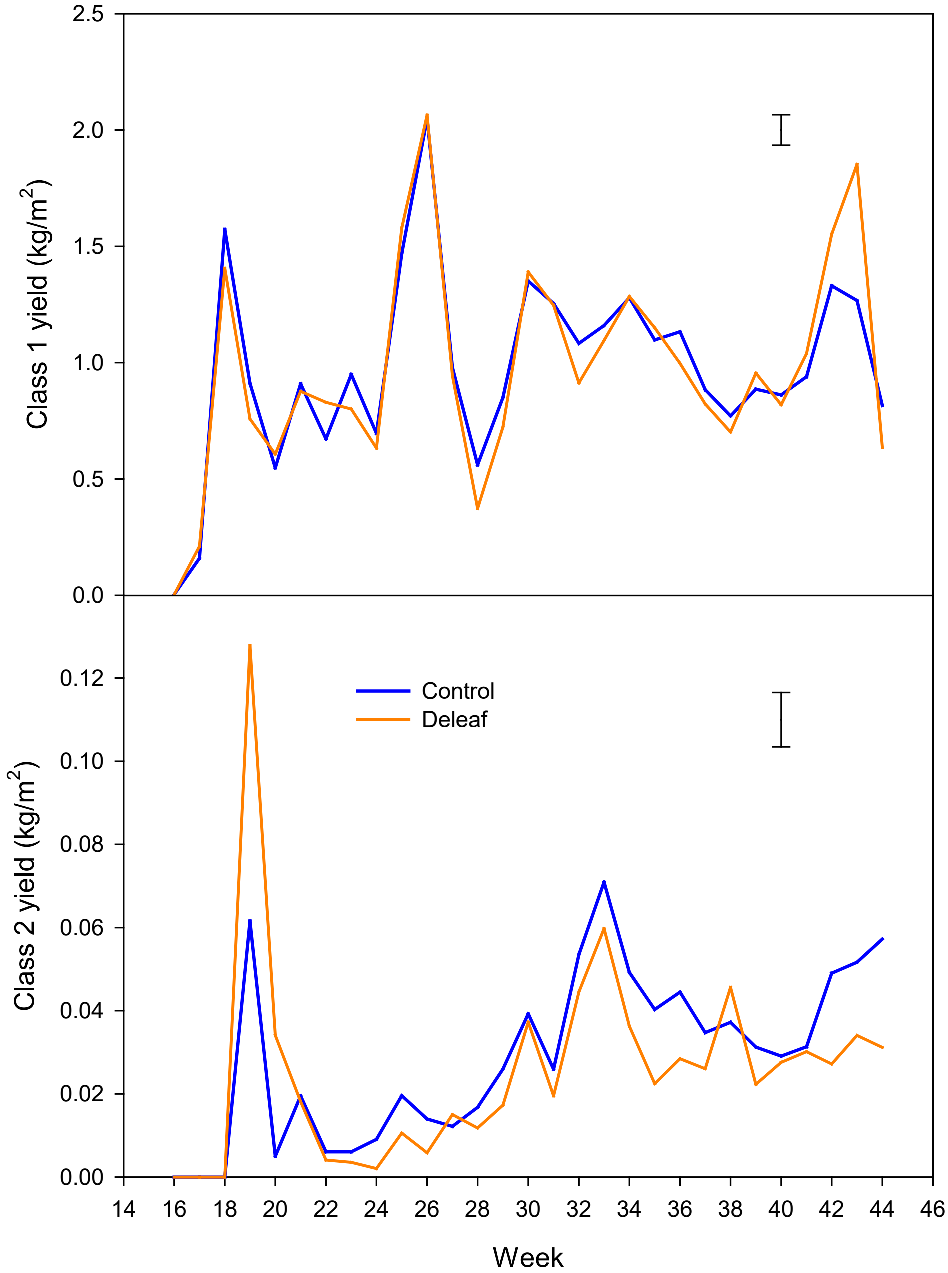

Figure 15. *The weekly yield of class 1 and class 2 fruits from the deleafed and control areas. The bars represent a pooled standard error of difference for comparing two means in any given week.*

Disease monitoring

Stem lesions

Browning at fruit removal wound sites was visible at the first assessment on 3 June, before the deleafing treatment had started. More wound sites were partially brown (i.e. over part of the cut surface) than completely brown, and none caused plant wilting. Around 17% of the total fruit removal wound sites had some degree of browning. There was no effect from deleafing treatment or row position on the number of wound sites with browning at this time (Table 3). It is considered likely that some of this tissue browning was due to a physiological cause (wound healing) rather than fungal infection. Isolation from stem fruit removal wound site tissues that had started to spread, cut out by nursery staff from another house, resulted in consistent recovery of a *Fusarium* sp. (16/17 samples) and no other fungal pathogens.

***Table 3**: Effect of deleafing and row position on occurrence of stem wound site browning in pepper, cv. Cupra – 2009.*

Factor and Treatment	Mean number of fully brown wound sites[a] per quarter row		Mean total[b] number of brown wound sites per quarter row	
	3 June[c]	27 Aug	3 June	27 Aug
Deleafing				
Control	1.1	6.9	20.9	31.9
Deleafed	1.9	4.6	19.9	34.6
Significance	NS	NS	NS	NS
LSD	-	-	-	-
Row Position				
Gutter	1.7	5.6	19.0	33.6
Ridge	1.3	5.9	21.6	32.9
Significance	NS	NS	NS	NS
LSD	-	-	-	-
Deleafing x Row position				
Control – gutter	1.1	5.4	17.5	25.4
Control – ridge	1.1	8.5	24.0	38.5
Deleaf – gutter	2.3	5.9	20.5	41.9
Deleaf – ridge	1.5	3.3	19.2	27.4
Significance	NS	NS	NS	0.023
LSD	-	-	-	16.59

[a]Full is browning across all the wound site surface.
[b]Total browning = Full + partial browning (partial is browning across part of the surface).
[c]Baseline levels before deleafing treatment commenced.

Plot size = one quarter of a row length, assessing the stem of both heads (ie 48 plants x 2 heads = 96 stems).

A greater number of partially and fully brown stem wound sites were found on 27 August than on 3 June (Table 3). This was not unexpected as a greater number of fruit had been cut from each stem by this time. There were no spreading lesions, wilted plants or missing stems. Neither the deleafing treatment nor row position significantly affected the number of fully brown wound sites. There was a significant (P <0.05) deleafing treatment x row position interaction on the total number of wound sites with any browning, the greatest number (41.9 per 96 stems) being in a deleafed gutter row and the least (25.4 per 96 stems) in a control gutter row.

Spreading lesions on the stem were first observed in late September, at various heights from the 'V' near the stem base up to around 2 m in height. A total of five spreading lesions were found on stems in the four monitored rows in the control area (1,536 stems in total), and two in the four monitored rows in the deleafed rows. The number of missing stems in each of these areas, assumed to be due predominately to stem lesions, was 10 in the control area and 16 in the deleafed area. There was no significant effect from deleafing or row position on the combined totals of stem lesions and missing stems (Table 4). Isolation tests confirmed that the majority of stem lesions observed in crops were associated with *Botrytis cinerea* (10/14 lesions tested), while some (3/14) were associated with *Fusarium* sp. As in 2008, the *Fusarium* sp. isolated from stems and fruit appeared identical in culture and was probably *F. oxysporum* or a closely-related species.

***Table 4**: Effect of de-leafing and row position on occurrence of spreading stem lesions, or missing stems on pepper, cv. Cupra – 20 October 2009.*

Factor and treatment	Total number spreading lesions or missing stems per quarter row[a]	Number spreading lesions in stem-V per quarter row
De-leafing		
Control	1.0	0.3
De-leafed	1.1	0.1
Significance	NS	NS
LSD	-	-
Row position		
Gutter	0.8	0.0
Ridge	1.4	0.4
Significance	NS	0.024
LSD	-	0.32
Deleafing x row position		
Control – gutter	0.6	0.0
Control – ridge	1.4	0.5
De-leaf – gutter	0.9	0.0
De-leaf – ridge	1.4	0.3
Significance	NS	NS
LSD	-	-

[a]48 plants and 96 stems per quarter row length

Internal fruit rot

Laboratory examination of visibly sound fruit collected on 20 October revealed that many were infected internally by *Fusarium* sp. (Table 5). The proportion of infected fruit was 35/101 (35%) in the control area and 41/108 (38%) in the deleafed area. Over both areas, the proportion of fruit affected on seed, or seed and internal wall, was 28.5% and 9.1% respectively. None was infected just on the internal wall. All of the 10 fruit with a small hole at the base were infected by *Fusarium* sp., but so were 66 fruit without a hole at the base.

***Table 5**: Effect of deleafing and glasshouse block on Fusarium internal fruit rot in pepper, cv. Cupra – 2009.*

Location of Fusarium in Fruit	% Fruit affected		
	Block 4 (control)	Block 5 (Control)	Block 6 (Deleafed)
Seed	26	33	25
Seed & fruit wall	8	2	13
Total	34	35	38

These results suggest that in this experiment 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. Given that it was not possible to randomise replicated areas of leafed and deleafed crop in 2009, and the relatively low incidence of spreading stem lesions/missing plants in individual plots (around 1 per 96 stems at the end of cropping), it is suggested that disease monitoring continues in any further work on deleafing in order to gain firmer results.

Nursery fruit wastage

The proportion of total fruit yield classed as wastage, 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 6). There was a large difference in wastage between the two control glasshouse blocks before, during and after the end of deleafing, with more than twice as much wastage in block 4 than block 5 in all periods. Wastage in block 6 (deleafed) was similar to that in block 5 (control). The proportion of fruit wastage increased significantly ($P < 0.05$) as the season progressed from 0.4 to 2.4% in block 4, 0.2 to 1.2% in block 5 and 0.1 to 0.6% in block 6.

***Table 6**: Effect of deleafing and glasshouse block on proportion of total fruit yield classed as wastage primarily due to Fusarium rot – 2009.*

Cropping period	Deleafing activity	% fruit classed as waste by weight (kg) (with standard errors)		
		Block 4 Control	Block 5 Control	Block 6 Deleafed
wk 12 - wk 23	Before first deleaf	0.4 (0.05)	0.2 (0.03)	0.1(0.03)
wk 24 - wk 37	During deleafing	1.9 (0.06)	0.6 (0.04)	0.6 (0.04)
wk 38 - wk 45	After last deleaf	2.4 (0.11)	1.2 (0.08)	0.6 (0.05)
Throughout season	-	1.8 (0.05)	0.7 (0.03)	0.5 (0.03)

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) in which crop treatment was identical. In the period after the last deleafing (weeks 38-45), fruit wastage in the deleafed block (0.6%) was lower than in both the control blocks (2.4 and 1.2%). This is the period in which the visible difference between treatments in the length of deleafed stem at the base of plants was greatest. Further work is required to determine if this difference is a real effect.

Interestingly, in an examination of the effect of summer shading on fruit wastage in these three blocks in 2007, the proportion of waste fruit (from week 26 to 35) was again greater in block 4 (control) than in block 5 (control) or block 6 (shaded).

Discussion

The initial assumption that the leaf area in sweet peppers can be reduced without sacrificing yield has again been proved correct. This is consistent with previous studies on tomato (Adams *et al*., 2002; Jones, 1979; Stacey, 1983; Wolk *et al*., 1983) which showed that around 50% of the older leaves can be removed in tomato without any loss in yield. This also backs up the conclusion from the first year's work where different leaf removal treatments were applied to individual (replicated) rows, and modelling of canopy photosynthesis which indicated that the top 40 cm of canopy probably account for over 60% of the gross photosynthesis. In the second year we choose to leave 1.6 m of leaf on each shoot, although due to the fact that transpiration can be desirable for cooling in summer and slightly more leaf may be needed when light levels are high, the amount of leaf was allowed to increase slightly over the summer. Dueck *et al*. (2006) predicted the bottom 62.5% of the canopy was a net sink (-0.3% of photosynthesis) but was responsible for 37% of the transpiration. Therefore, while it might be possible to leave less than 1.6 m of leaf and still not affect yield, this has not been tested experimentally.

Reduced transpiration would be expected as a consequence of reducing the leaf area (Adams *et al*., 2002). However, it was not possible to quantify any saving in terms of water uptake as part of this project. Problems arose due to the reliability of the drain measurement kit which kept blocking. Furthermore, this only measured the run off from relatively few plants and so was not necessarily representative of the whole block. Ideally any follow on work would look at the run off from a number of whole rows in each treatment.

The independent temperature/humidity sensors showed that the deleafed block was less humid and sometimes slightly cooler. This may in part be because of the reduced transpiration and the effect that this had 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 highlights the need for accurate measurement. With a wet and dry bulb system, relatively small errors in the measurement of temperature (within the manufacturers' specifications) can have a surprisingly large impact on the humidity control and energy use. A 0.3°C error, as occurred here, could account for around a 2.5% difference in RH. If both wet and dry bulbs were 0.3°C out, with one reading high and the other low, the RH error would be around 5%. Furthermore, any errors in the dry bulb temperature directly affect the heating demand and, therefore, energy use.

The reduction in transpiration as a result of deleafing should result in energy savings. Greenhouse energy balance models indicate that around half of the savings are likely to be due to reduced need for humidity control. However, the precise impact on energy use will be heavily dependent on the humidity control strategy, particularly the influence on minimum pipe. Deleafing should also result in less heating demand. Transpiration acts to cool the greenhouse, which in summer can be beneficial, but at other times the cooling increases the heating required to maintain a desired temperature. In this experiment there were clearly energy savings in the latter part of the year after deleafing. However, due to intrinsic differences between blocks and the subtle difference in humidity control, it is 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. It is suggested that if the work is repeated, switching the treatments around would help to gain greater certainty of the potential energy savings.

The two fungi most commonly found causing stem lesions of pepper in the UK are *Fusarium* sp. and *Botrytis cinerea*. There may be advantages from deleafing in terms of reduced disease risk due to lower RH's, and the fact that lower stems should be cleaner and dryer following the removal of old leaf. However, there is also a potential risk that deleafing may increase stem fungal diseases due to the creation of an increased number of wound sites. The work in year one indicated that wound sites created by deleafing were not highly susceptible to *Fusarium* sp. or *Botrytis cinerea.* However, no firm conclusions could be drawn due to the low incidence of stem disease (four lesions), and the benefits of potentially lower RH's could not be observed until all of the plants in a block was deleafed in the same way. In the 2009 experiment, the number of brown wound sites increased in August when compared to early June, although there was no significant effect of deleafing. Spreading lesions (mainly due to *Botrytis cinerea*) first appeared in late September, but again there was no significant effect of the deleafing treatment. Given that the treatments are not replicated and that there may be some inherent differences between compartments it would be beneficial to repeat these assessments.

While deleafing is unlikely to have a direct effect on Fusarium internal fruit rot, a change in the microclimate around flowers and developing fruit could have an indirect effect and so this was 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.

In reality there will be a trade off between energy use and the achieved RH/HD. In this work the same RH settings were used in both compartments. The achieved RH was slightly lower in the deleafed compartment, but this was mainly because of the issues with sensor calibrations. However, it would have been possible to adjust the humidity control settings so that a similar amount energy was used and the achieved RH was even lower in a deleafed compartment. Under these circumstances it is possible that deleafing may have a more positive impact on the incidence of disease.

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