Project title	Cucumber: A technical and economic evaluation of the high wire crop training system
Project number:	PC 273
Project leaders:	Dr R J Jacobson RJC Ltd and Cucumber Growers' Association Mr D Hargreaves Derek Hargreaves Horticultural Consultancy and Cucumber Growers' Association
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Location of project:	Glen Avon Growers, Park Lane, Cottingham, East Yorks, HU16 5RX
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Date project completed:	31 January 2009
Key words:	cucumber, high wire production, labour use, technology transfer

The results and conclusions in this report are based on an investigation conducted over a two-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

I 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.

Mr D Hargreaves
Technical Officer
Cucumber Growers' Association

Signature .... Date ....

Report authorised by:

Dr R J Jacobson
Secretary and Communications Officer
Cucumber Growers' Association

Signature .... Date ....

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Grower Summary

Headline

- High wire growing regimes, as evaluated in this project, were not economically viable compared to the conventional cordon system.
- Several technical difficulties would have to be overcome before the high wire growing system could be successfully adopted by UK growers.

Background and expected deliverables

A recent HDC funded project (PC201) evaluated the technical and economic viability of all year round (AYR) cucumber production using supplementary lights, climate control screens and energy efficient practices. Although the studies were technically successful, energy costs substantially increased during the project and there were difficulties associated with operating CHP plants; both of which eroded the financial margins that had originally made AYR cucumber production look a potentially attractive option. As a consequence, it seems unlikely that UK growers will adopt the whole AYR production package in the near future.

The AYR growing system incorporated a high wire crop training system that was novel to UK growers. There were found to be considerable benefits from growing cucumbers by this training system under the AYR regime, including simplified evaluation of crop performance and crop management decisions, improved light penetration to the fruit, good air circulation, easier fruit picking, better quality, reduced wastage and improved management of foliar pests and diseases.

The high wire system involves training a single stem up a vertical string to a horizontal support wire positioned about 3.8-4.2m above ground. As the plant approaches the wire, it is layered so that only the most recent 2.8-3.2m of growth is ever vertical. As a consequence, the younger and most productive leaves are continually positioned to maximise light interception and this is a key factor in obtaining higher yields. The conventional "cordon" growing system currently used by virtually all UK cucumber growers differs from this because the main growing points are removed when the main stem first reaches the wire and two lateral shoots are then allowed to cascade downwards to a length of approximately one metre.

Information gathered from overseas about the required inputs and returns of the high wire growing system was extremely variable and UK growers had no means of determining beyond doubt the accuracy of the claims. The CGA decided that the potential benefits of this system should be properly evaluated and this was the basis of this project.

In summary, the overall aim of the project was to determine and demonstrate the technical and economic viability of the high wire crop training system to UK cucumber growers. The specific objectives were:

1. To continue to gather information about high wire crop training from overseas.
2. To quantify the output from a high wire cucumber crop training system in the UK.
3. To quantify inputs required to achieve the above objective.
4. To compile and collate comparative data from current commercial "best practice".
5. To calculate economic margins for high wire cucumber crops.
6. To transfer new knowledge and technology to cucumber growers.
7. To provide direction for complementary studies.

Summary of the project and main conclusions

The facility and approach

Previous work in small experimental glasshouse units had illustrated the importance of assessing growing systems, and in particular labour inputs, on a relevant scale. Therefore, two adjacent and near identical 0.5ha commercial glasshouses were chosen for the study. The glasshouses were already fitted with thermal screens, a Brinkman Alliance control system (identical to Priva Integro) to monitor and control all environmental systems, and purpose built equipment to monitor irrigation requirements. One glasshouse was fitted with additional equipment required to grow high wire trained crops, while the other provided a comparison with best current conventional practice. The previous experience of growing high wire crops in the AYR production project indicated that a grow pipe positioned approximately 450mm above the top of the rockwool slab was required to more effectively manage the growing environment. Other new equipment included a Nomad labour recording system to accurately record all staff inputs, heat meters to monitor energy use and two hydraulic trolleys to enable staff to work efficiently at variable heights in the crop.

The Dutch "Qlipper" system was used to layer the crop. This consisted of one thin metal rod per plant, which was suspended from the crop support wire and carried two clips to grip the plant stem. As the plant grew, the lower clip was removed and the stem was slid down the rod within the higher clip. The clip that was previously in the lower position was now replaced in the higher position. The crop was layered in this manner twice weekly. Side shoots and lower leaves were removed twice weekly as separate exercises. The crop wire was initially positioned 4.15m above ground but this was lowered to 3.6m for the second season in an attempt to reduce the labour required for harvesting.

The project ran over two growing seasons. The required equipment was installed at the start of the first season. Cordon crops were then grown in both glasshouses for approximately three months to obtain base line environmental data and quantify any inherent differences between the compartments. Both glasshouses were replanted in April 2007, when the high wire system was introduced, and then again in July 2007.

Several changes were made to the high wire growing regime for the second growing season in an attempt to reduce costs and increase production. The most significant change was a reduction from three to two sequential crops, thus reducing the period that the glasshouse was out of production by three weeks.

The CGA Technical Officer and the host grower planned the agronomic strategy and monitored the crops on a day to day basis. FEC services were commissioned to record and report on all matters related to environmental control and energy use. The expertise of other specialists was sought as required.

Agronomic summary

The first and last cordon crops were planted at a density of 1.5 plants / m^2, with the middle cordon crop being planted at 2.0 plants / m^2, reflecting common commercial practice in the UK. When these plants reached the support wire, the main growing points were removed and two lateral shoots were taken per plant, thus providing 3 heads / m^2. In order to produce an equivalent leaf area in both crops, the first high wire crop in year one was planted at the higher density of 3 plants / m^2. The second high wire crop was planted in July at the intermediate density of 2 plants / m^2 because it was to be grown under shortening days which would eventually become limiting. In the second year, the first high wire crop was planted at 1.5 plants / m^2 and extra heads were taken in March to increase the density to 3 plants / m^2. The second high wire crop was planted in early-June at 3 plants / m^2 with the intention of reducing the head number as days shortened, although this proved unnecessary.

The cultivar Aviance was chosen for all crops with the exception of the two middle crops in year one (cv Eminentia) and the second high wire crop in year two (part cv Filia).

All crops were grown using a conventional temperature regime. This began at 20°C for two days and then increased to 22 °C during the day to establish the crop. After 10 days, the regime was changed to 20.5+1.5 °C day / 19°C night to promote crop vigour. Once the crop was being harvested, the pre-night (*i.e.* from one hour before sunset to four hours after sunset) was lowered to 14 °C to maintain vigour.

Cucumbers were thinned to one fruit to every two leaves throughout both high wire crops. A similar strategy was adopted in the cordon crops until they reached the support wire but all fruit were allowed to develop thereafter.

The irrigation need for the high wire crop was found to be greater than the standard regime, which started two hours after sunrise and ended two hours before sunset applying up to 3ml / J / m^2. As a consequence, applied levels for the high wire grown plants were therefore increased up to 3.5ml / J / m^2.

Plant growth and production

The high wire crop training system was evaluated under very dull and challenging growing conditions in 2007 and 2008. The total light sum in 2008 was the lowest recorded for ten years and most UK cucumber growers suffered lower than average yields. The high wire system is designed to maximise the use of available light and it suffered disproportionately compared to the conventional system during these dull periods. In addition, fluctuating daily conditions experienced during 2008 made it impossible to control growth by matching leaf number to available light.

Control of plant vigour presented one of the greatest challenges to effective crop management in both seasons. This was in part due to the characteristics of the available cultivars but was exacerbated by the poor light and variable conditions. This was reflected in lower than anticipated yields.

In the first year, the high wire system had produced nearly 11 cucumbers per m^2

more than the cordon system by mid-October. However, the final cordon crop remained in the glasshouse longer than the high wire crop and produced another 1.9 cucumbers per m^2 thus reducing the final balance to just over 9 cucumbers per m^2.

In the second year, the output from the high wire system was 15 cucumbers / m^2 ahead of the cordon system by early August but then production declined and by mid-September yields were similar. The high wire crop was in very poor condition by mid-October and was terminated four weeks before the final cordon crop. As a consequence, the cordon system had produced five more cucumbers / m^2 at the end of the season.

Labour inputs

One of the main considerations in this project was to compare the labour requirements of high wire and conventional cordon-trained crops. The tasks and labour input were similar until the plants reached the support wire but thereafter became very different. In the cordon crop, a large proportion of the labour was then devoted to finding and picking fruit that were in random positions within the proliferation of foliage. By contrast, in the high wire system, a smaller proportion of time was devoted to picking because the location of the fruit was predictable and they were easily accessible. Instead, more labour was required to remove side shoots and unwanted fruit, remove old leaves and layer the plants.

At the end of the 2007 season, 60% more person-hours had been devoted to the high wire crop than the cordon crop. The additional cost was approximately £2.31 / m^2. Further analysis of the data from the high wire crop showed that crop work and harvesting accounted for 62% and 38% of the total labour input respectively. Equivalent figures for the cordon crop were 44% and 56%.

The changes made for the 2008 season slightly reduced the labour input to the high wire crop, which resulted in 55% more person-hours being devoted to the high wire crop at an additional cost of £2.12 / m^2. However, the balance between crop work and harvesting was almost identical to 2007.

It is quite clear that additional labour costs remain one of the greatest obstacles to the uptake of the high wire growing system in the UK. The project team have identified two opportunities for further savings; *i.e.* i) the use of moveable crop support wires to optimise the height of the crop for each task and ii) the use of ultra-violet light to remove redundant leaves. However, both techniques would increase set up costs.

Pest and disease

In the AYR cucumber production project the incidence of foliar pest and disease was much reduced compared to commercial crops because there were no old leaves on the plants to harbour the causal organisms. However, it was unclear whether this would still be the case without the use of supplementary lights because crop growth would be slower and leaves would remain on the plants longer.

In these trials, routine releases of *Encarsia formosa* (on cards) and *Amblyseius cucumeris* (in sachets) were made from planting against glasshouse whiteflies and western flower thrips respectively. Both pests were present in small numbers throughout the growing season but no further action was required. However, biological control of two-spotted spider mites (TSSM) with *Phytoseiulus persimilis* was not effective during the summer months and the resulting pest damage contributed to poor plant vigour and lower than anticipated yields.

The difficulties in trying to control TSSM with biological control agents in a high wire crop are two-fold. First, TSSM tend to move to the highest points of the crop during the summer while *Phytoseiulus* prefer more shaded positions lower down the plant where it is cooler and more humid during the day. Second, in a high wire crop the growing points are always at the highest position and therefore suffer the most concentrated and sustained attacks from TSSM. The combined effect is that TSSM population growth is unrestrained in the heads of the plants, plant growth is slowed and TSSM feeding becomes concentrated on the same few leaves. This exacerbates the overall effect and it is not long before plant's growing point is destroyed.

Powdery mildew was more problematic in the high wire crop than in the previous AYR project despite all cultivars having some level of tolerance to the pathogen. Overall, the incidence of this disease was comparable to the cordon crop and similar numbers of fungicidal treatments were applied between March and September. *Mycosphaerella* and *Botrytis* were present on plants in both growing systems from April / May onwards and similar numbers of fungicidal treatments were required to keep these diseases under control.

Energy use

Greenhouse internal environment and weather data were recorded using the site climate control computer and data was downloaded via modem connection by FEC consultants. Data collected and analysed included set points for heating and ventilation temperature, heating pipe temperature, vent position and screen position, as well as greenhouse temperature, humidity deficit, CO_2, ambient temperature and solar radiation. In addition, heat meters were installed to monitor heat use (as hot water) in the pipe rail system in the cordon crop, the pipe rail system in the high-wire crop and the grow pipe system in the high-wire crop.

In 2007, the high-wire system in the three crop regime consistently used more heat per m^2 than the cordon crop . In total this represented a difference of 39.5 kWh / m^2 (20.6%). However, a more representative indicator of energy efficiency is kWh / cucumber produced. On this basis the high-wire crop still used more than the cordon crop although the difference was less (9.5%). The changes made in the 2008 season successfully reduced energy use in the high wire crop so that it was only

2.6% greater per cucumber produced. If the yield increases required for economic viability can be achieved in the future, then the high wire system could deliver an actual reduction in energy use per cucumber produced.

Financial benefits

Prior to this project, reports from the Netherlands suggested that yields of 220 cucumbers per m^2 per annum were possible from high wire grown cucumber crops without supplementary lighting. This was about 60 cucumbers per m^2 per annum greater than the higher yielding cordon-trained British crops in modern glasshouses. At an average value of 22p per cucumber, this equated to £132k per ha per annum. The initial investment in the infrastructure of the glasshouse was relatively modest (initially estimated to be c£60k per ha) and, if this were true, the new growing system would provide a very rapid payback for growers.

In 2007, there were approximately 37 ha of glasshouses owned by CGA members in the UK which would be suitable for high wire production. Therefore, the potential increase in value to the UK industry of adopting high wire production could have been £4.88m. Furthermore, all new and replacement glass would have been suitable for high wire production.

The high wire system provided better economic returns in a three sequential crop growing regime than in the alternative two crop regime. At best, the high wire yields were about 7% greater than the conventional cordon crop but the additional value of that produce did not offset the higher costs of labour, consumables and energy. An additional 19.7 cucumbers per m^2 would have been required from the three crop regime for it to match the conventional regime. It is interesting to note that Dutch advisers have now revised their yield estimates for high wire production and the growing system has lost popularity in the Netherlands during the course of this project.

Further technological developments would be required to reduce production costs for the high wire system before it could be successfully implemented in the UK. However, this would require additional investment in the glasshouse infrastructure which couldn't be justified at this time.

Action points for growers

- The high wire growing regimes, as evaluated in this project, were not economically viable compared to the conventional cordon system currently used by the majority of cucumber growers in the UK.
- The system was evaluated under very dull and challenging growing conditions in 2007 / 2008. The results would probably have been better in a year with a higher total light sum such as 2003. Alternatively, the use of supplementary lighting (as in the AYR project, PC 201) would have provided a base level of light that would have maintained assimilate production and crop vigour during the periods of poor natural light.
- It is recommended that the following technical issues be addressed before growers undertake any further large scale trials:

    - Specialised cucumber cultivars are required which are more suited to the high wire method of production.
    - Improved methods of managing plant vigour are required, particularly during dull and / or fluctuating weather conditions.
    - More rapid and effective methods of controlling spider mites are required.
    - Labour costs must be reduced. This could probably be achieved by investing in moveable crop wires and automated removal of redundant leaves.

- This project has been a success for the UK cucumber industry in that it has provided a thorough crop-scale evaluation of this growing system without individual members wasting their own time and resource on duplicated independent trials.

SCIENCE SECTION

INTRODUCTION

Background

A recent HDC funded project (PC201: Jacobson, Hargreaves & Pratt, 2007) evaluated the technical and economic viability of all year round (AYR) cucumber production using supplementary lights, climate control screens and energy efficient practices. Although the studies were technically successful, energy costs substantially increased during the project and there were difficulties associated with operating CHP plants; both of which eroded the financial margins that had originally made AYR cucumber production look a potentially attractive option. As a consequence, it is unlikely that UK growers will adopt the whole AYR production package in the near future.

The AYR growing system incorporated a high wire crop training system that was novel to UK growers. There were found to be considerable benefits from growing cucumbers with this training system under the AYR regime, including simplified evaluation of crop performance and crop management decisions, improved light penetration to the fruit, good air circulation, easier harvesting, better fruit quality and reduced wastage. In addition, the incidence of foliar pest and disease was much reduced in the AYR system because there were no old leaves to harbour the causal organisms. However, it was unclear whether this would still be the case without the use of supplementary lights because crop growth would be slower and leaves would remain on the plants longer.

CGA members decided that the potential benefits of the high wire system of training cucumbers to the UK industry should be properly evaluated independently of supplementary lights.

Commerial objectives

As a first step in the evaluation of the high wire system, CGA Officials sought information from Dutch growers who were already trialling the system. Initial reports from The Netherlands suggested that yields of 220 cucumbers per m^2 per annum were possible from high wire grown cucumber crops without supplementary lighting (S. Lambert, Rijk Zwaan, Pers. Comm., September 2006). This was about 60 cucumbers per m^2 per annum greater than the higher yielding conventional (*i.e.* cordon-trained) British crops grown in glasshouses over 4m high (to the gutter). At an average value of just 22p per cucumber, this equated to £132k per ha per annum. However, it was known that Dutch growers often include all cucumbers in yield records, while British growers only count Class I produce, so these figures could have been artificially high. A more conservative yield estimate of 190 cucumbers per m^2 per annum would still have equated to an additional value of £66k per ha per annum. However, UK growers had no means of determining beyond doubt the accuracy of the Dutch claims.

In 2007, there were approximately 37 ha of glasshouses owned by CGA members in the UK which would be suitable for high wire production. The potential increase in value to the UK industry of adopting high wire production was therefore estimated to be in the range of £2.4m to £4.8m. Furthermore, all new and replacement glass would be suitable for high wire production.

The initial investment in the infrastructure of the glasshouse appeared to be relatively modest (initially estimated to be c£60k per ha). If this were true, the new growing system would provide a very rapid payback for growers.

CGA members were sceptical about the predicted benefits of the high wire system because it was known that there were additional costs associated with the high wire system that had not yet been quantified. For example, HDC Project PC201 had included a desk study of labour inputs for different crop training practices. This had indicated that high wire training required considerably more labour than the conventional cordon system but the reported differences varied tremendously.

Given such varied information about the required inputs and returns, the CGA decided that the data would have to be validated in practical trials. If high wire production was shown to be technically and economically viable then it was highly likely that it would be rapidly adopted by a significant proportion of UK cucumber growers. If not, then this project would prevent many individual CGA members from wasting their own time and resource with independent trials.

Technical objectives:

In summary, the overall aim of the project was to determine and demonstrate the technical and economic viability of the high wire crop training system to UK cucumber growers. The specific objectives were:

1. To continue to gather information about the high wire crop training systems
2. To quantify the output from a high wire cucumber crop training system in the UK.
3. To quantify inputs required to achieve the above objective.
4. To compile and collate comparative data from current commercial "best practice".
5. To calculate economic margins for high wire cucumber crops.
6. To transfer new knowledge and technology to cucumber growers.
7. To provide direction for complementary studies.

The approach

Previous work in small experimental glasshouse units had illustrated the importance of assessing growing systems, and in particular labour inputs, on a relevant scale. Therefore, two similar modern commercial glasshouses (each of 0.5ha), which were owned and managed by a leading CGA grower member, were chosen for the study. One glasshouse was fitted with the equipment required to grow high wire trained crops, while the other provided a comparison with best current conventional practice.

The CGA Technical Officer and the host grower planned the agronomic strategy and monitored the crops on a day to day basis. FEC services were commissioned to oversee, record and report on all matters related to environmental control and energy use. The expertise of other specialists was sought as required.

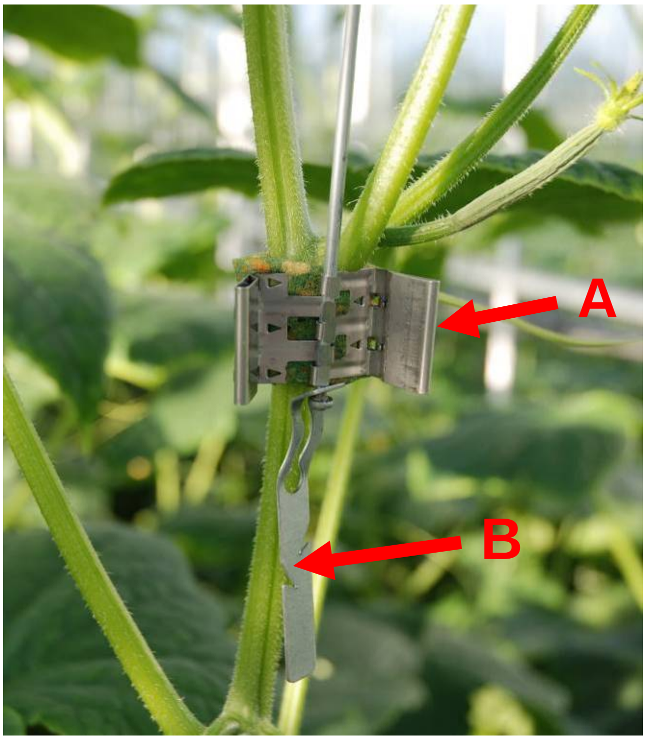
The project was designed as an HDC / CGA demonstration project for the cucumber industry. The dissemination of new information was an integral part of the work plan and was done via existing channels throughout the project.

The high wire and cordon crop training techniques

The high wire (or layered) system involves training a single stem up a vertical string to a horizontal support wire positioned about 3.8-4.2m above ground. As the plant approaches the wire, it is layered so that only the most recent 2.8-3.2m of growth is ever vertical. Standard tomato layering hooks could have been used to support the plants but this uses non-compostable polypropylene string. The project team adopted the lower labour input "Qlipper" system (Figures 1 and 2).

Figure 1. The Qlipper crop support system in situ

Figure 2. Close up view of the Qlipper crop support system showing one clip at the bottom of the suspended metal rod (item A) and the attachment (item B) for the jute string which initially guides the plant stem to the first clip (see Figure 4).



The Qlipper system consists of one thin metal rod per plant, which is suspended from the crop support wire and carries two clips to grip the plant stem. As the plant grows, the lower clip is removed and the stem is slid down the rod within the higher clip. The clip that was previously in the lower position is now replaced in the higher position. The crop is layered in this manner twice per week. Side shoots and lower leaves are removed twice per week.

The conventional "cordon" growing system currently used by virtually all UK cucumber growers differs from this because the main growing points are removed when the main stem first reaches the wire and two lateral shoots are then allowed to cascade downwards to a length of approximately one metre. Crop work is similar to the high wire system until the plants reach the wire but thereafter "sub-lateral" shoots are encouraged and unwanted shoots are removed relatively infrequently.

In summary, the high wire system plants continually grow upwards while the cordon system plants cascade downwards for most of their cropping life. As a consequence, the younger and most productive leaves of the plants in the high wire system are continually positioned to maximise light interception.

Summary of work completed in the first year of the project

A complete record of the results from the first year of the project may be found in the Annual Project Report (Jacobson, Hargreaves & Pratt, 2008). In summary:

The facility

One glasshouse was fitted with the equipment required to grow high wire trained crops, while the other provided a comparison with best current conventional practice. The previous experience of growing high wire crops in the AYR production project indicated that a grow pipe positioned approximately 450mm above the top of the rockwool slab was required to more effectively manage the growing environment. Other new equipment included a Nomad labour recording system to accurately record all staff inputs, heat meters to monitor energy use and two hydraulic trolleys to enable staff to work efficiently at variable heights in the crop. The project was planned to run over two growing seasons. The required equipment was installed at the start of the first season. Cordon crops were then grown in both glasshouses for approximately three months to obtain base line environmental data and to determine whether there were any inherent differences that would have to be taken into account at a later stage. Both glasshouses were replanted in April, when the high wire system was introduced, and then again in July. These crops were primarily used to sort out teething problems, bring crop workers up to speed with the new crop training methods, gain experience of managing the new crop environment and make initial observations of pest and disease incidence.

Agronomic study

As previously stated, the first crops were both grown by the conventional cordon training system to compare the glasshouses. In week 15 2007, after 9 full weeks of production, the two cordon crops had produced 29.44 and 30.05 cucumbers per m^2. The difference of 0.61 cucumbers per m^2 (*i.e.* 2% greater in the conventional comparison house) was considered to be within an acceptable parameter. However, there were found to be small "energy use" differences between the two blocks and all the energy data quoted in the main body of this report was adjusted accordingly.

The second cordon crop was planted at a density of 2 plants / m^2 and the third at 1.5 plants / m^2, reflecting common commercial practice in the UK. When these plants reached the support wire, the main growing points were removed and two lateral shoots were taken per plant, thus providing 4 and 3 heads / m^2 respectively. In order to produce an equivalent leaf area in both crops, the first high wire crop was planted at the higher density of 3 plants / m^2. A different strategy was adopted for the second high wire crop because it was to be grown under shortening days which would eventually become limiting to production. In this case, the crop was planted at the intermediate density of 2 plants / m^2.

All crops were grown using a conventional temperature regime. This began at 20°C for two days and then increased to 22 °C during the day to establish the crop. After 10 days, the regime was changed to 20.5+1.5 °C day / 19°C night to promote crop vigour. Once the crop was being harvested, the pre-night (*i.e.* from one hour before sunset to four hours after sunset) was lowered to 14 °C to maintain vigour.

Cucumbers were thinned to one fruit to every two leaves throughout both high wire crops. The same strategy was adopted in the cordon crops until they reached the support wire but all fruit were allowed to develop thereafter.

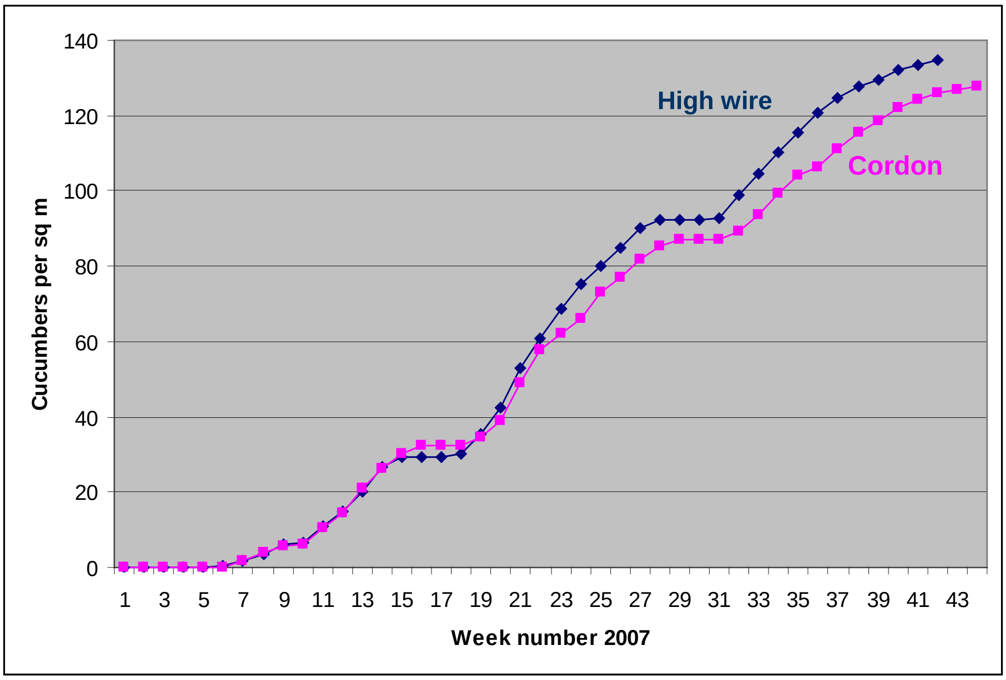
The irrigation need for the high wire crop was found to be greater than the standard regime, which started two hours after sunrise and ended two hours before sunset applying up to 3ml / J / m^2. Applied levels for the high wire grown plants were therefore increased up to 3.5ml / J / m^2.

The cumulative yields in the high wire and conventional crops are shown in Figure 3. They were almost identical during the first cropping period when both glasshouses contained conventional crops. Thereafter, the high wire system gradually moved ahead and had produced 10.98 more cucumbers per m^2 by week 42. However, the cordon crop remained in the glasshouse longer than the high wire crop and produced another 1.94 cucumbers per m^2 thus reducing the final balance to 9.04 cucumbers per m^2.

The production from the high wire system was considerably lower than anticipated. This was attributed to the very poor light levels during important periods of the second and third crops. The high wire system is designed to maximise the use of available light and therefore suffered disproportionately compared to the conventional system during these conditions.

Based on this information, the duration of each high wire crop was considered too short to gain the maximum potential of the growing system. In 2008, the high wire strategy was changed to two crops; planted in January and June.

Figure 3. Cumulative yield in high wire and conventional crops in 2007



Labour inputs

One of the main considerations in this project was to compare the labour requirements of high wire and conventional cordon-trained crops. The tasks and labour input were similar until the plants reach the support wire but thereafter became very different. In the cordon crop, a large proportion of the labour was then devoted to finding and picking fruit that were in random positions within the proliferation of foliage. By contrast, in the high wire system, a smaller proportion of time was devoted to picking because the location of the fruit was predictable and they were easily accessible. Instead, more labour was required to remove side shoots and unwanted fruit, remove old leaves and layer the plants. Analysis of the Nomad records for the cordon crop showed that crop work and harvesting accounted for 44% and 56% of the total labour input respectively. Equivalent figures for the high wire crop were 62% and 38%.

At the end of the season, Nomad records confirmed that one extra person-year had been devoted to the high wire crop, which was in line with expectations. The project team believed that the time devoted to harvesting could be reduced in the high wire crop by lowering the crop wire and this was done for the 2008 season.

Pest and disease incidence

In the previous AYR production project, the incidence of foliar pest and disease was much reduced because there were no old leaves present in the crop to harbour the causal organisms. However, it was unclear whether this would still be the case without the use of lights because crop growth would be slower and leaves would remain on the plants longer.

Routine releases of *Encarsia formosa* and *Amblyseius cucumeris* were made from planting against *Trialeurodes vaporariorum* (glasshouse whitefly) and *Frankliniella occidentalis* (western flower thrips) respectively. Both pests were present in small numbers throughout the growing season but no further action was required.

There were no significant pest problems in the first high wire crop but a large population of *Tetranychus urticae* (two-spotted spider mite) developed in the second crop. This was not exclusive to the high wire system but the pest was more damaging to this crop during late summer when the mites congregated in the heads of plants. Biological control of *T. urticae* with *Phytoseiulus persimilis* was not very effective at that time and the infestations were finally brought under control by high volume applications of Oberon (spiromesifen) and Dynamec (abamectin).

Sphaerotheca fuliginea (powdery mildew) was also more problematic in the second high wire crop than in the previous AYR project but no more so than in the cordon crop grown for comparison in this project. A total of five treatments of Systhane (myclobutanil), Rubigan (fenarimol) or Fungaflor (imazalil) were required between

June and October to keep the pathogen under control in the high wire crops, while eight treatments were applied to the cordon crops.

Didymella bryoniae (Mycosphaerella) and *Botrytis cinerea* (grey mould) also presented more difficulty than anticipated, with greater losses in the second high wire crop than in the equivalent cordon crop. A total of four treatments of Repulse (chlorothalonil), Bravo (chlorothalonil) or Rovral (iprodione) (alone or in tank mixes with Switch [cyprodinil plus fludioxonil]) were applied between May and October to suppress the development of these pathogens in the high wire crops, while only three were applied to the cordon crops.

Energy use

The high-wire crop consistently used more heat per m^2 than the cordon crop. In total this represented a difference of 39.5 kWh / m^2 (20.6%). However, a more representative indicator of energy efficiency is kWh / cucumber produced. On this basis the high-wire crop still used more than the cordon crop although the difference was less (9.5%).

MATERIALS AND METHODS

The facility and equipment

The location and glasshouses:

The two chosen glasshouses are located at Glen Avon Growers Ltd (Park Lane, Cottingham, East Yorkshire), which is a 4.2ha nursery in the heart of the northern cucumber growing area. It is also the administrative base of the Cucumber Growers' Association.

The two adjacent glasshouses are of near identical construction, similar size and share one common interior wall. Specifications include:

- The glasshouse housing the cordon crop is 81.2m long and comprises 10 full (plus 1 part) 6.4m Venlo double bays (orientated north-south) giving 5,216.5m^2 floor area.
- The glasshouse housing the high wire crop is 81.2m long and comprises 10 full 6.4m double Venlo bays giving 5,196.8m^2 floor area.
- Central 3m wide concrete road running east-west
- Height to gutter is 5m from top of concrete dolly and 5.7m to the top of the ridge
- Roof glazing is 1.125m wide glass
- Triple pane ventilators, fitted for independent control on both sides of the ridge in staggered formation, giving 24% ventilation over floor area. All ventilators fitted with rubber seals.
- Raised troughs supported by trellis hooks are installed throughout the growing area lifting the rockwool slabs approximately 450mm from the ground (Figure 4).
- Slab moisture content, EC and run off were monitored using purpose built equipment supplied by Hortitechnik. This system measured the slab moisture content and EC with a Delta T probe and measured run-off by actual volume.
- Ludvig Svensson SLS 10 Ultra Plus material is used over the entire growing area (Figure 4). The properties of the fabric include thermal insulation, diffuse light transmission, vapour transmission and minimal pack size when drawn back (*i.e.* open). The screen installation is fitted with a slipping clutch system, which simplifies the opening / closing mechanism, and reduces pack size when closed.
- Heating and carbon dioxide are supplied from a range of sources. The main source is a gas fired hot water boiler with a heat base load back up from coal during the winter. There is also a 3 MW combined heat and power (CHP) system providing hot water and carbon dioxide to the unit. Hot water is circulated via conventional pipe loops (51mm dia.) between each row. An additional "grow pipe" (33 mm dia.) was added to improve air circulation in the taller high wire crop (see section 2.1.2).

- A Brinkman Alliance (*i.e.* identical to Priva Integro) control system is used to monitor and control the environment in the glasshouse and irrigation system. Control extends to all environmental systems including heating, screens, ventilation, irrigation and CO_2 enrichment.

Additional installations for high wire production:

The previous experience of growing high wire crops in the AYR production project (PC 201) indicated that a grow pipe positioned approximately 450mm above the top of the rockwool slab was required to more effectively manage stem diseases (Figures 4 and 5).

The high wire crop training system required the installation of new crop support wires, initially positioned 4.15m above ground. A Qlipper support rod with two clips was suspended from that crop wire for each plant. Additional supports were required for the horizontal stems after crop layering began (Figure 5).

Other equipment included two hydraulic trolleys to enable staff to work efficiently at variable heights in the crop and a Nomad labour recording system to accurately record all staff inputs. The approximate cost of the main items for this 5,196m^2 installation was £44.2k:

	£k
<u>Installations</u>	
• Grow pipe	19.8
• Layering supports	0.7
• Additional crop wires and supports	3.5
• Labour associated with above items	0.9
<u>Other equipment</u>	
• Part cost of Nomad labour recording system (optional)	4.1
• Two hydraulic trolleys	6.0
• Qlipper clips	<u>9.2</u>
<u>Total</u>	44.2

Figure 4. View across one side of the high wire glasshouse on 19 April 2007, showing the position of the raised troughs, the grow pipe and the initial crop training system which uses jute string to support the stems until they reach the hanging Qlipper supports. (Note that the screens are part closed).

Figure 5. View down row immediately after replanting the high wire crop in July 2007. This clearly shows the position of the grow pipe (item A) and crop layering supports (eg item B).

Cropping strategy

One of the conclusions from the first year of the project was that the duration of the individual high wire crops had been too short to gain the maximum potential of the growing system. Following discussions with colleagues in the Netherlands, it was decided to change the strategy for high wire production to two crops for the 2008 season. This would reduce the period that the glasshouse was out of production by three weeks, potentially allowing more than 20 additional fruit to be produced. This change was not appropriate for the cordon crop because the quality of the fruit would not be maintained after production progressed to lateral growth.

To optimise high wire production from two crops, the plant density would have to be matched to the ambient growing conditions. This would mean starting at a low plant density and then increasing the number of plant heads when there was adequate natural light. The increase would be achieved by allowing side shoots to develop but this would also depend on the plants' ability to produce and sustain those shoots, which declines as the plants age. As an overall compromise, it was decided to plant the high wire crop two weeks later than the cordon crop and take the extra shoots in mid-March. The first high wire crop would then continue at the higher density until early-mid June.

In-crop measurements

Weekly measurements of leaf numbers and dimensions were made to calculate the Leaf Area Index (LAI) based on published methods (Xiaolei & Zhifeng, 2004; Blanco & Folegatti, 2003). This involved measuring the length and width of fully expanded leaves, applying a constant factor and then multiplying by the number of leaves per m^2. The accuracy of the published data was checked in preliminary practical trials as it differed from information provided by Marcelis (Wageningen University, pers. comm., 2007). The adopted LAI was subsequently used as a means of quantifying crop vigour (see section 2.4.). Further weekly measurements were taken of stem diameter and the position / number of fruits on the stem.

All labour input was recorded in separate task categories and automatically logged on the nursery computer using the Nomad Labour Recording System.

All produce leaving the glasshouses was graded in the on-site pack house and the numbers of cucumbers in each marketing category were automatically recorded on the nursery computer.

Greenhouse internal environment and weather data were recorded using the site climate control computer and data was downloaded via modem connection by FEC consultants. Data collected and analysed included set points for heating and ventilation temperature, heating pipe temperature, vent position and screen position, as well as greenhouse temperature, humidity deficit, CO_2, ambient temperature and solar radiation. In addition, heat meters were installed to monitor heat use (as hot water) in the pipe rail system in the cordon crop, the pipe rail system in the high-wire crop and the grow pipe system in the high-wire crop.

Pests and diseases were monitored on a daily basis by nursery staff and twice weekly by the crop consultant. In addition, the local representative of the Biological Control Supplier and an independent IPM specialist visited the crop at 1- 2 week intervals.

Crop management decisions

The CGA Technical Officer and the host grower planned the agronomic strategy and monitored the crops on a day to day basis in consultation with other specialists such as representatives from the relevant seed houses.

Decisions regarding crop management were based on the general appearance of the crop, leaf area index, plant vigour, rate of growth, fruit production, data collected from the various sources detailed above and weather forecasts.

RESULTS AND DISCUSSION

Agronomic Summary

Crop diary

		Week number 2008	
		High wire house	**Conventional house**
First crop (cv Aviance)	Planting date	4	1
	First harvest	8	6
	Plants stopped	22	Not applicable
	Crop terminated	24	17

Second crop (cultivar ⁎)	Planting date	24	17
	First harvest	27	20
	Plants stopped	Not stopped	Not applicable
	Crop terminated	41	28
Third crop (cv Aviance)	Planting date	-	29
	First harvest	-	32
	Plants stopped	-	Not applicable
	Crop terminated	-	45

⁎ Conventional - cv Aviance
High wire - part cv Aviance and part cv Fila with single bays of cv Amazone and cv 24-162(RZ)

Growing regime

The cropping strategy is described in section 2.2. The three cordon crops were planted at densities of 1.5, 2 and 1.5 plants / m^2 respectively, which reflected common commercial practice in the UK. When cordon-trained plants reach the support wire, the main growing points are removed and two lateral shoots are taken per plant, thus providing 3 heads / m^2. In order to produce an equivalent leaf area in both crops, the first high wire crop was planted at 1.5 plants / m^2 and extra heads were taken in March by removing growing points and allowing two shoots to develop from leaf 24; thereby increasing the density to 3 heads / m^2. The original intention had been to increase the head number by taking one side shoot from each plant but the vigour of those shoots was very poor compared to the original heads and this made it very difficult to manage and layer the crop effectively. The second high wire crop was planted in week 24 at a density of 3 plants / m^2.

Cucumbers were thinned in the high wire crops by removing every other fruit, which has become common practice across northern Europe except where small fruits are still acceptable to customers (*eg.* in Finland). This provides a simple system of one fruit to every two leaves that is easily followed by crop workers and puts minimal stress on the plants.

All crops were grown using a conventional temperature regime with similar use of pre-nights to influence plant vigour. This began at 20°C for two days and then increased to 22°C during the day to establish the crop. After 10 days, the regime was changed to 20.5+1.5°C day / 19°C night to promote crop vigour. Once the crop was being harvested, the pre-night (*i.e.* from one hour before sunset to four hours after sunset) was lowered to as low as 14 °C to maintain plant vigour. Manipulating (*i.e.* reducing) the pre-night temperature had less effect on the plant vigour than expected, which was attributed to the characteristics of the cultivars being grown. It should be noted that the powdery mildew resistant cultivars which are currently commercially available do not lend themselves to this method of production. Other cultivars are required which can be more readily manipulated to control plant vigour.

The standard irrigation regime started 2 hours after sunrise and ended 2 hours before sunset, applying up to 3ml / J / m^2. As in 2007, this proved to be too little for the high wire crop, even during the poorest light conditions. As a consequence, applications to the high wire crop were increased to up to 3.5ml / J / m^2. It is possible that the additional volume of irrigation contributed to the extra heat input required to maintain acceptable humidity deficits in the high wire crop (see Section 3.2.).

As in 2007, control of plant vigour presented the greatest challenge to effective crop management. This was in part due to the characteristics of the available cultivars but was exacerbated by the extremely variable summer weather in 2008.

Figure 6a shows the comparative light levels in 2006, 2007, 2008 and the twenty year average. The total light sum for 2008 was substantially less than the two previous years. In fact, the total light sum in 2008 was the lowest since 1998 (Figure 6b). Furthermore, there were extreme day to day differences during 2008 which are not evident in the week by week comparisons shown in Figure 6a.

There were marked reductions in plant vigour when the daily light level suddenly changed from very good to very poor, particularly when the plants were carrying a large number of leaves.

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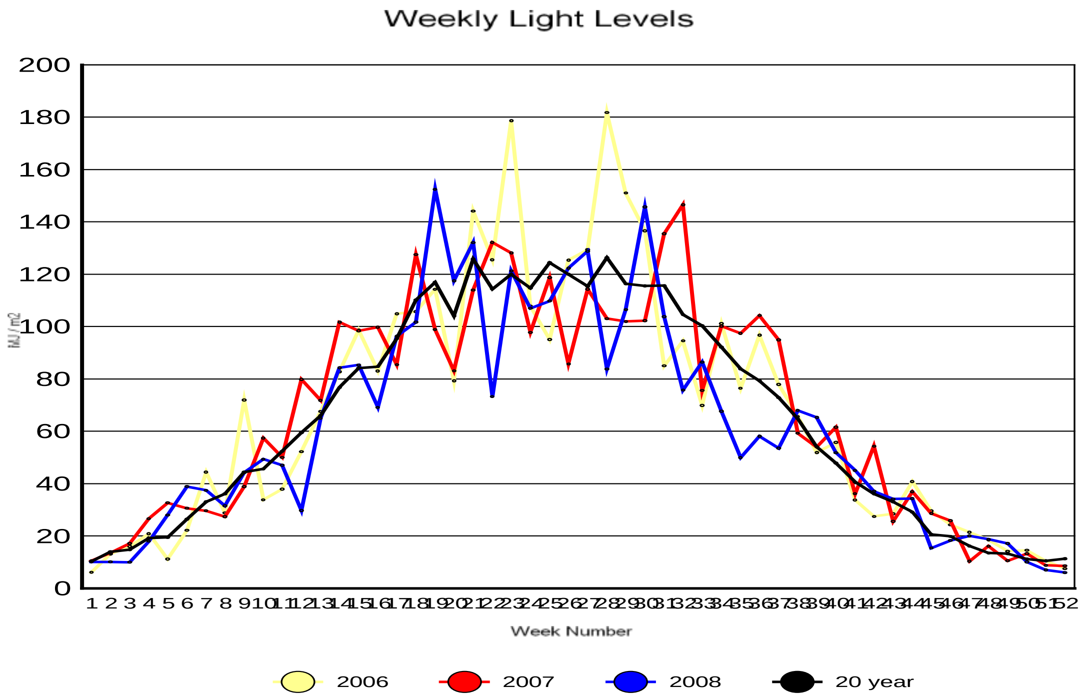
Figure 6a. Comparative light levels in 2006, 2007, 2008 and the twenty year average (all expressed as weekly totals in MJ/m²) are shown in the upper chart. For clarity, the data for 2008 and the long term average have been separated and are also shown in the lower chart.



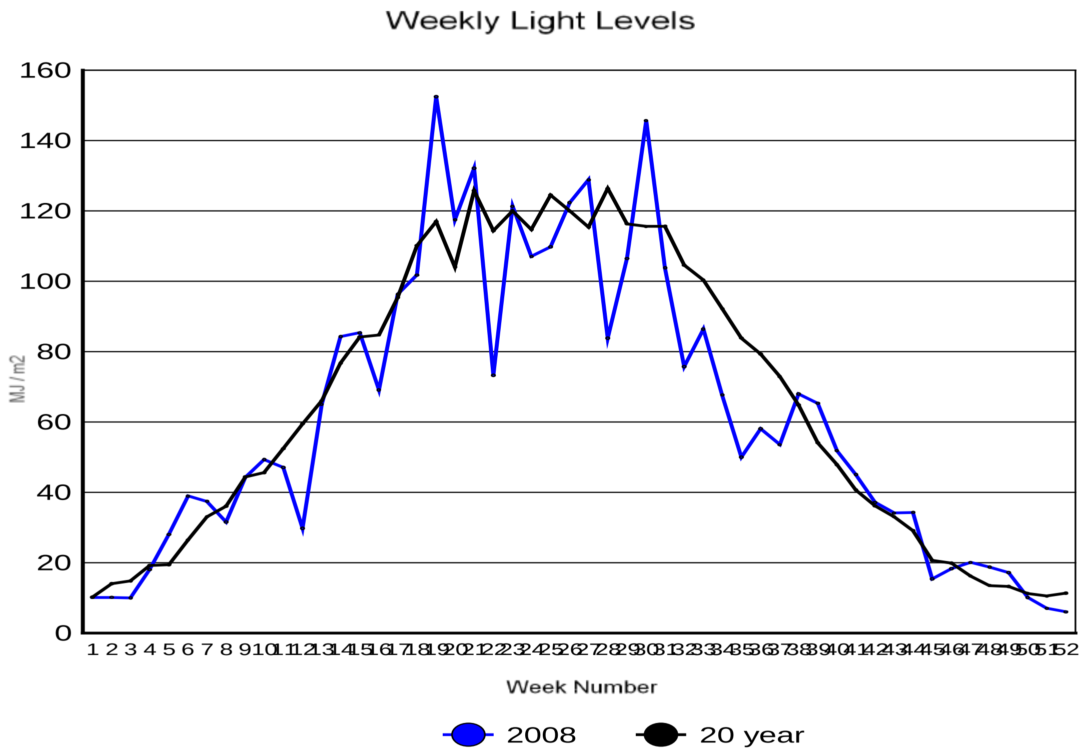
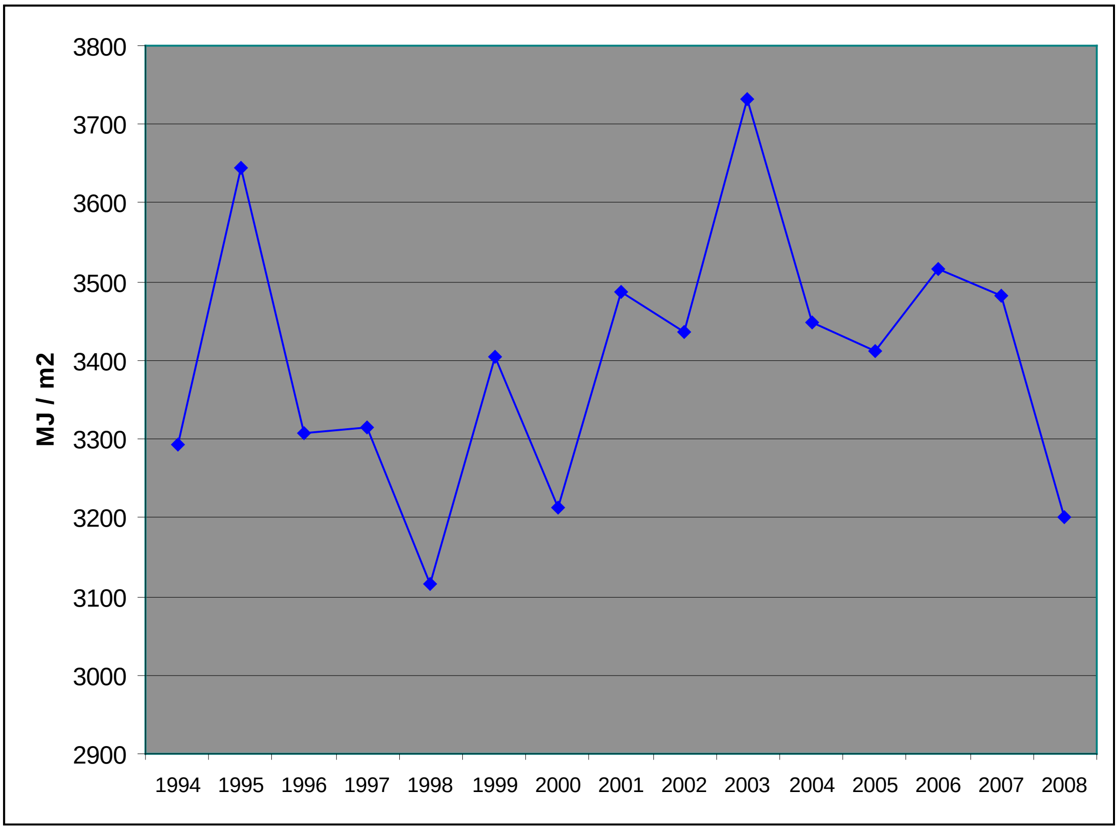


Figure 6b. Total annual light sum (MJ /m^2) from 1994 to 2008

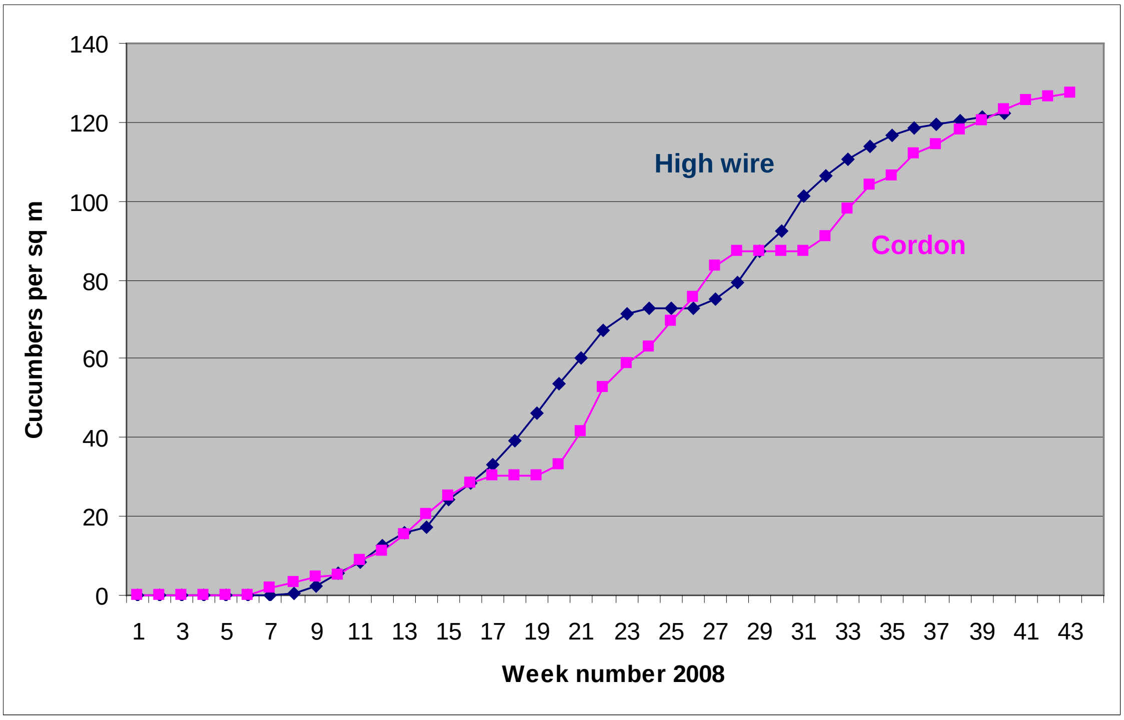


The aim was to control plant vigour by maintaining a LAI of 3.0 or slightly less (L. Marcelis, Wageningen University, pers comm., 2007), which would be achieved by retaining 16 to 22 leaves on each plant. In combination with crop density, this provided a reasonable balance between too many and too few leaves per m^2 and was relatively easy to accomplish during normal weather conditions. However, the optimum LAI reduces as light levels decline and it was impossible to make appropriate adjustments to leaf number during the fluctuating weather conditions. As a consequence, the use of LAI did not provide a satisfactory means of managing plant vigour during the periods of very poor natural light (*eg.* weeks 22 to 23 and 28 to 29). It is important to note that where supplementary lighting is available, as was the case in HDC project PC 201 (Jacobson, Hargreaves & Pratt, 2007), it can be used to provide a base level of light that will maintain assimilate production and a satisfactory LAI during periods of poor natural light.

Production data

The cumulative yields in the high wire and conventional crops throughout the whole 2008 season are shown in Figure 7. Although the first high wire crop was planted two weeks later than the first cordon crop, early yields from the high wire crop were greater and at the end of March the total output was similar from both crops. During the following four months, it was difficult to draw direct comparisons between the two glasshouses because they were replanted at different times. However, in early August, after all the replanting had been completed, the total production from the high wire system was 15 cucumbers / m^2 ahead of the cordon system. From then on, production from the high wire crop declined and by mid-September the total output was once again similar to the cordon crops. The second high wire crop was in very poor condition by mid-October and was terminated four weeks before the third cordon crop. The high wire system had produced about five less cucumbers / m^2 by the end of the season.

Figure 7. Cumulative yield in high wire and conventional crops in 2008



As in 2007, the production from the high wire system was considerably lower than anticipated (see Section 1.6). This was largely due to the difficulty in maintaining the vigour of the available cultivars during periods of very poor light and fluctuating weather conditions (see Section 3.1.2.). However, there is little doubt that the vulnerability of the high wire grown plants to spider mite damage (see Section 3.1.5.) also had a major impact on yield.

Comparison of data presented for 2007 in Figure 3 and for 2008 in Figure 7 clearly shows that the output of the high wire system was greater in the three crop regime in 2007 than in the two crop regime in 2008. Furthermore, the performance of the high wire system relative to the conventional cordon system was considerably better in the three than two crop regime. The combined results from both years indicate that the three crop regime is more suitable than the two crop regime for high wire cucumber production. This is at least in part because the three crop regime allows more flexibility in managing crop vigour and spider mites.

Labour

At the end of the 2007 season, the Nomad records showed that 60% more person-hours had been devoted to the high wire crop than the cordon crop. The additional cost was approximately £12k. Further analysis of the data from the high wire crop showed that crop work and harvesting accounted for 62% and 38% of the total labour input respectively. Equivalent figures for the cordon crop were 44% and 56%.

Changes were made for the 2008 season with the aim of reducing the labour input to the high wire crop. In particular, the crop support wires were lowered to 3.6m so that mature fruit would be more accessible and less time would be spent harvesting. It was also anticipated that some savings in labour use would be gained from reducing the number of times the high wire crops were replanted.

Overall, there was a slight improvement in 2008, with 55% more person-hours being devoted to the high wire crop than the cordon crop. The additional cost was reduced to approximately £11k. However, the breakdown of the high wire crop data showed the balance between crop work and harvesting to be almost identical to 2007.

It is quite clear that additional labour costs remain one of the greatest obstacles to the uptake of the high wire growing system in the UK. The project team have identified two further opportunities for savings:

1. Moveable crop support wires.

   The ability to adjust the height of the crop to the optimum height for each task would simplify many routine activities and should provide substantial savings. In particular, it would no longer be necessary to grow young plants up a string before transferring them to the clips on the Qlipper rods. There would be other potential savings in the time required to pick fruit and remove redundant leaves. However, the installation of such a system would be a major undertaking and require considerable additional investment. Furthermore, it would be impossible to install in many existing glasshouse structures in the UK. Moveable crop wires had been considered for the second year of this project but there were insufficient available funds. It is interesting to note that the most modern cucumber growing facility in the UK, which was built during the second year of this project, does include moveable crop wires for a system that the grower describes as "partial high wire".

2. Automated leaf removal.

   The use of ultra-violet light for removal of redundant leaves is being investigated in the Netherlands and the initial costs do not appear to be prohibitive. A prototype system was considered for the second year of this project but rejected at that stage because it was not proven technology and there were unresolved Health and Safety considerations.

Pest and disease

In the HDC-funded AYR cucumber production project (PC 201; Jacobson, Hargreaves & Pratt, 2007) the incidence of foliar pest and disease was much reduced compared to commercial crops because there were no old leaves on the plants to harbour the causal organisms. However, it was unclear whether this would still be the case without the use of lights because crop growth would be slower and leaves would remain on the plants longer.

In these trials, routine releases of *Encarsia formosa* (on cards) and *Amblyseius cucumeris* (in sachets) were made from planting against *Trialeurodes vaporariourum* (glasshouse whiteflies) and *Frankliniella occidentalis* (western flower thrips) respectively. Both pests were present in small numbers throughout the growing season but no further action was required.

There were no major pest problems in the first high wire crop but a large population of *Tetranychus urticae* (two-spotted spider mite [TSSM]) developed in the second crop. This was consistent with the first year of this project (Jacobson, Hargreaves & Pratt, 2008) but was in contrast to experiences in the AYR project (Jacobson, Hargreaves & Pratt, 2007).

An important component of this project was to evaluate opportunities to reduce chemical pesticide use via the high wire crop training system, so control of TSSM focused on the predatory mite, *Phytoseiulus persimilis*. We persevered with this biological control measure for as long as possible but it eventually became clear that the predators were not going to prevent severe damage to the heads of the plants. The TSSM population was finally brought under control by repeated high volume applications of Dynamec (abamectin) and Oberon (spiromesifen) but not before the pest had a detrimental effect on plant vigour.

The difficulties in trying to control TSSM with biological control agents in a high wire crop are two-fold. First, TSSM tend to move to the highest points of the crop during the summer while *Phytoseiulus* prefer more shaded positions lower down the plant where it is cooler and more humid during the day. Second, in a high wire crop the growing points are always at the highest position and therefore suffer the most concentrated and sustained attacks from TSSM. The combined effect is that TSSM population growth is unrestrained in the heads of the plants, plant growth is slowed and TSSM feeding becomes concentrated on the same few leaves. This exacerbates the overall effect and it is not long before plant's growing point is destroyed. Furthermore, all side shoots are removed from plants in high wire crops making recovery impossible in many cases. In contrast, after a cordon crop has reached the support wire, the highest points of the plants are older leaves, which are of much less importance to growth, and the plants are able to continually grow away from the worst TSSM damage.

The use of a three crop regime for high wire production reduces the overall impact of TSSM damage because there is an opportunity for a fresh start in late summer. However, this increases the overall cost of the production system. It is important to note that Dutch growers have access to a greater range of effective acaricides, which they use as primary control measures against TSSM, and they do not therefore consider this pest to present a constraint to high wire crop production. There is little doubt that any further development of the high wire production system in the UK must incorporate a more rapid and effective control measure against TSSM than is currently available.

Sphaerotheca fuliginea (powdery mildew) continued to be more problematic in the high wire crop than in the previous AYR project but no more so than in the cordon crop grown for comparison in this project. All cultivars used had some level of powdery mildew tolerance. A total of eight treatments of Systhane (mycobutanil), Rubigan (fenarimol) or Fungaflor (imazalil) were required between March and September to keep the pathogen under control in the high wire crops, while seven treatments the same range of fungicides were applied to the cordon crops.

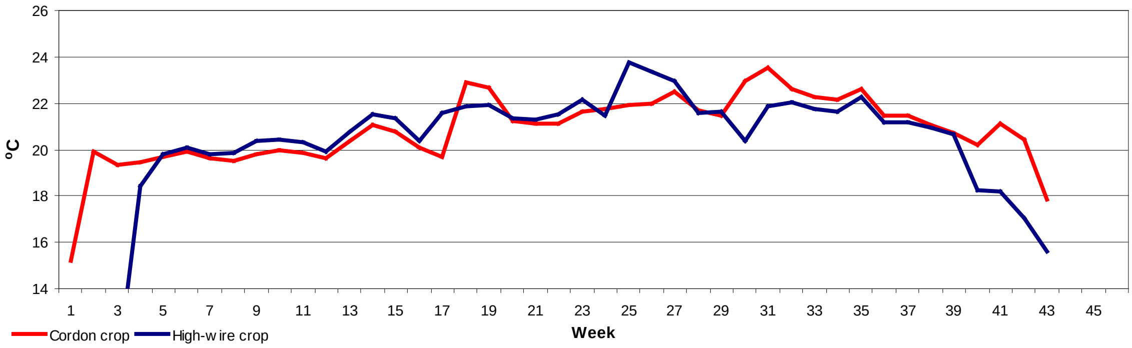
Initially, *Didymella bryoniae* (Mycosphaerella) and *Botrytis cinerea* (grey mould) were less of a problem in the 2008 season than the 2007 season, probably due to improved use of the grow-pipe to maintain air movement through the crop. However, the severity of stem disease caused by these pathogens increased during the summer. Pathogen establishment may have been assisted by our attempts to maintain the LAI around 3 (see Section 3.1.2.) which restricted air movement around the stems. A total of five treatments of Bravo (chlorothalonil) or Switch (cyprodinil and fludioxonil) (alone or in tank mixes with Rovral [iprodione]) were applied between April and September to suppress the development of these pathogens in the high wire crops, while only three such sprays were applied to the cordon crops.

Cropping environment and energy inputs

Greenhouse environment data

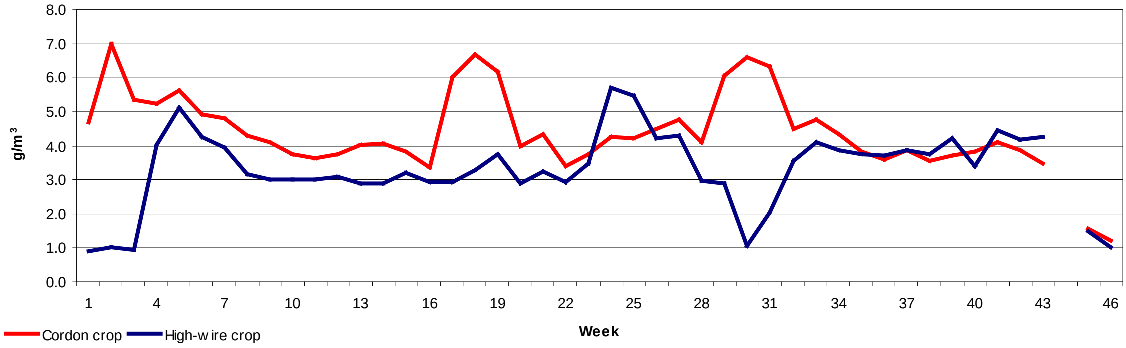
Greenhouse temperatures in both houses, throughout the season, are shown in Figure 8. The shorter growing year associated with the high-wire crop is responsible for the later increase in greenhouse temperature (week 3) and the earlier decrease. However, there was relatively little difference between the average greenhouse temperatures through the year. It should be noted that the average greenhouse temperature for each treatment was set according to the needs of each crop; not to deliver identical growing conditions. This applied to all aspects of greenhouse climate control.

Figure 8 - Greenhouse temperature



The humidity deficit recorded in both houses, throughout the season, is shown in Figure 9. As in 2007, the general trend during 2008 was for the humidity deficit to be lower in the high-wire crop than in cordon crop. As can be seen in Figure 9 there were brief periods when the difference changed significantly; these periods coincided with crop removal and replanting (apart from week 30 in the high-wire crop when a measuring box was faulty).

Figure 9 - Humidity deficit



The data in Figure 10 shows that significantly higher CO_2 levels were achieved in the cordon crop up to week 16 even though similar set points were used. This was in spite of the fact that:

- Both crops received CO_2 from a common enrichment system, *i.e.* received the same amount of CO_2
- The CO_2 enrichment system only ran when both compartments required CO_2
- There were similar levels of venting in both compartments

Although it was not measured, it is expected that the larger active leaf area in the high wire crop meant that CO_2 was consumed faster than in the cordon crop. As CO_2 enrichment only took place when both compartments required it, the high-wire crop did not receive as much CO_2 as it required due to lower demand by the cordon crop restricting enrichment. It would therefore be reasonable to assume that this affected the yield of the high-wire crop during this period.

As the season progressed the CO_2 level in the cordon crop fell due to increasing amounts of venting. During this period the CO_2 levels in each compartment were broadly similar as CO_2 enrichment was required almost continuously during daylight hours in both compartments.

Figure 10 - Carbon dioxide

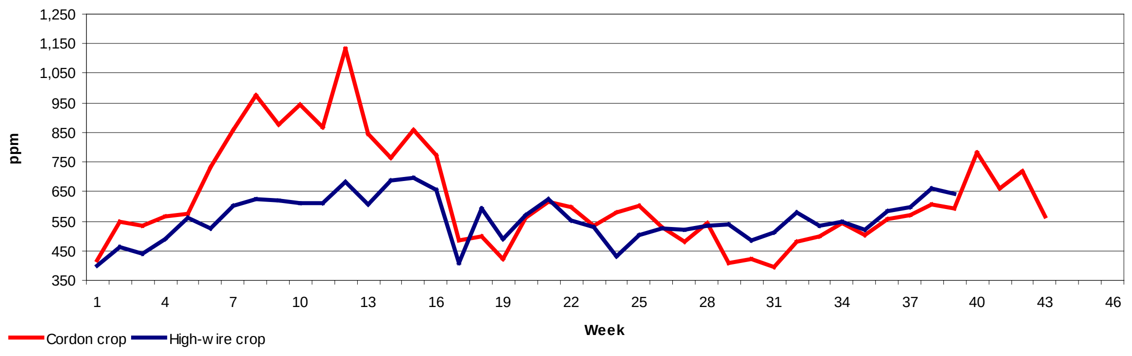
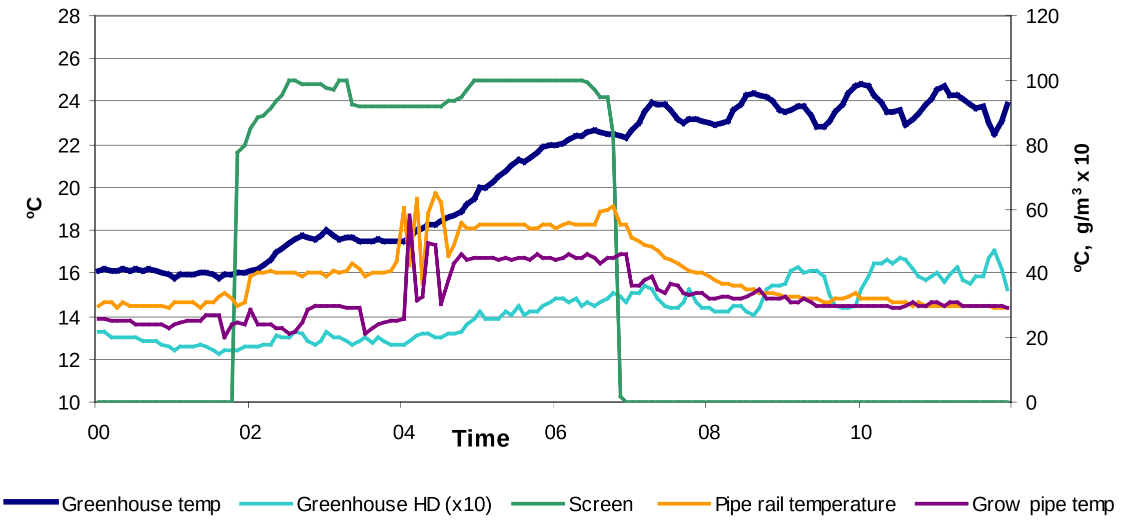


Figure 11 helps to provide an insight into the greenhouse environment and use of the grow pipe in the high-wire crop. From 02:00 to 06:00 the greenhouse temperature is steadily increased following the pre / post night period. The grow pipe is mainly used around sunrise to aid both humidity control and plant activity especially at the head of the plant. In this example the maximum grow pipe temperature was 45°C. However, when there was concern over disease or development of the head of the plant this was increased to 50°C.

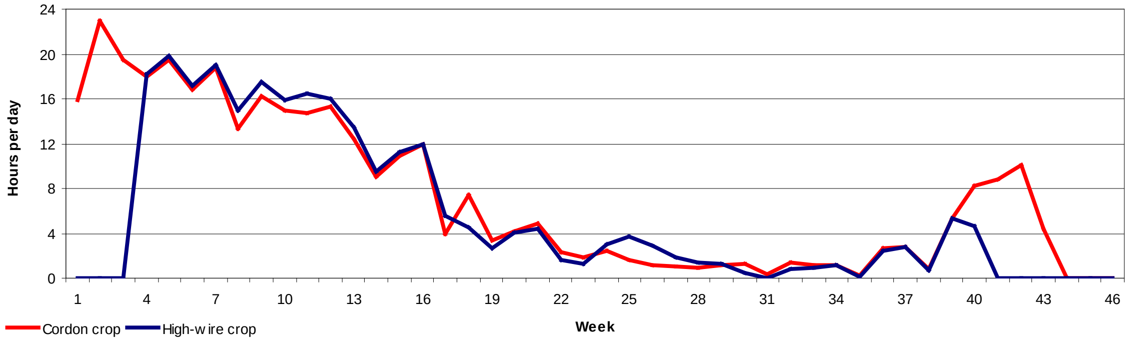
Figure 11 - A day in week 21



Thermal screens

Similar thermal screen control strategies were applied in both treatments and this is reflected in the comparable hours closed data shown in Figure 12.

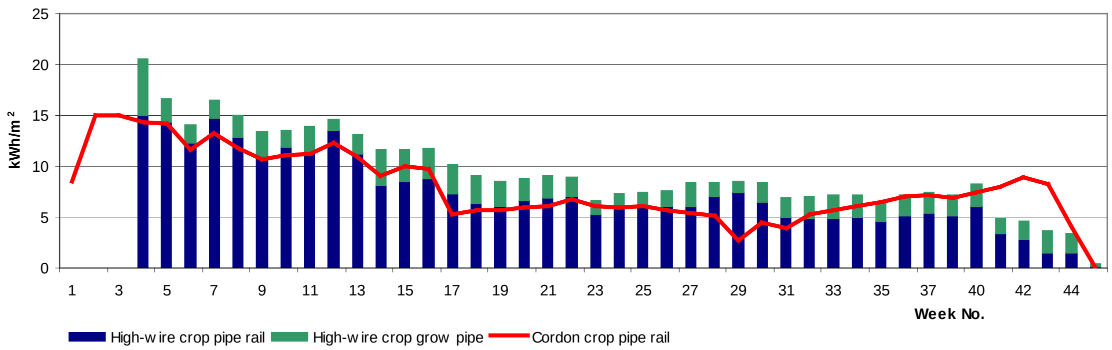
Figure 12 - Thermal screen hours



Energy data

Note that the following data is heat delivered as hot water to the greenhouses, not mains gas used. The data has also been normalised to account for the inherent differences between each compartment.

Figure 13- Heat use per week



Weekly energy use in the high-wire crop was consistently higher than in the cordon crop. This is the same trend as seen in 2007 and can be attributed to greater demand for humidity control. It is interesting to note that similar amounts of energy were used by the pipe rail in each treatment and the difference in total energy use was due to that used by the grow pipe.

Table 1 below details the total amount of energy used in each treatment during 2008. In spite of the higher energy use per week in the high-wire crop, the shorter cropping season meant that over the whole of 2008 it used a total of 340 kWh / m^2 compared to 346 kWh / m^2 in the cordon crop.

A more representative indicator of energy efficiency is kWh / cucumber produced. On this basis, the high-wire crop used 2.6% more energy per cucumber than the cordon crop, which was largely due to the lower yield.

Table 1. - Energy use per crop 2008

Year		Type	Date in	Date out	Days of cropping	Total heat use kWh/m²	Yield cucumber/m²	Specific energy consumption kWh/cucumber
2008	Crop 1	Cordon	03/01/2008	21/04/2008	109	189.1	30.6	6.19
2008	Crop 2	Cordon	24/04/2008	14/07/2008	81	67.9	56.9	1.19
2008	Crop 3	Cordon	17/07/2008	23/10/2008	98	88.6	40.0	2.22
2008	Crop 1	High-wire	23/10/2008	09/06/2008	138	219.1	72.6	3.02
2008	Crop 2	High-wire	12/06/2008	04/10/2008	114	120.9	49.5	2.44
Total for 2008		Cordon			288	346	127	2.71
		High-wire			252	340	122	2.78

Energy costs

Table 2 below shows the cost per m² and per cucumber assuming a boiler efficiency of 85%. For consistency, the cost of gas used for this calculation is the same as that used in the 2007 report; *i.e.* 2.0p/kWh including transport and metering charges.

Table 2 - Energy costs

Year		Type	£/m²	P / cucumber
2008	Crop 1	Cordon	4.45	14.5
2008	Crop 2	Cordon	1.60	2.8
2008	Crop 3	Cordon	2.08	5.2
2008	Crop 1	High-wire	5.16	7.1
2008	Crop 2	High-wire	2.84	5.7
Total crops 2008		Cordon	8.14	6.4
		High-wire	8.00	6.6

Overall the difference in energy cost per cucumber produced is relatively small (0.2p, 3%). It should be noted that these costs have been calculated on a flat rate cost of gas for the whole year. If growers buy gas on a monthly basis the later start with the high wire crop will mean reduced use during January this is when the gas prices are higher which will lead to lower total gas costs.

Economic evaluation of two high wire growing regimes

The economic returns from the two high wire growing regimes, relative to the standard cordon grown regime, are shown in Table 3. The standard crop is used as the base line and figures for the high wire crop are given as more or less than that norm. The cost of financing the loan for capital items has been spread over 5 years and the repayments have been averaged over that period so they appear the same for each year. The cost of labour, consumable items and energy were all reduced in year 2 as a result of the planned changes in growing practices.

Table 3. Economic returns from two high wire growing regimes relative to the standard cordon grown regime.

			£ / m^2	
Three crop high wire regime used in year 1	Costs	Capital (including finance)*	1.81	6.77
		Consumables	1.73	
		Labour	2.31	
		Energy	0.92	
	Income	10 more cucumbers / m^2 @ 22.8p each	2.28	
	Balance		- 4.5	
Two crop high wire regime used in year 2	Costs	Capital (including finance)*	1.81	3.95
		Consumables	0.15	
		Labour	2.12	
		Energy	- 0.13	
	Income	5 less cucumbers / m^2 @ 22.8p each	- 1.14	
	Balance		- 5.1	

* spread over 5 yrs

The results show that the three crop high wire regime provided a better economic return than the two crop alternative. However, both regimes provided poorer economic returns than the conventional cordon system and would remain less profitable than that system even after the loan for set up costs had been repaid.

An additional 19.7 and 22.4 cucumbers per m^2 would have been required for the high wire crops to match the conventional crops in years 1 and 2 respectively. If we had achieved the yields predicted by the Dutch consultants at the outset, then both high wire regimes would have been more profitable than the standard cordon growing system. It is interesting to note that the Dutch have now revised those estimates (N. Jongerius, Plantenkwekerij Jongerius Houten bv, 2008; Groenten en Fruit, 2008).

CONCLUSIONS

- Light levels were very poor during the summers of both 2007 and 2008, and UK cucumber growers suffered lower than average yields. The high wire system is designed to maximise the use of available light and suffered disproportionately compared to the conventional system during the dull periods. Furthermore, the fluctuating conditions during 2008 made it particularly difficult to control plant vigour. The high wire system was therefore evaluated under very testing conditions.
- Supplementary lighting (as used in project PC 201) provides a base level of light that can maintain assimilate production and crop vigour during periods of poor natural light. This would have overcome the problems encountered in this project.
- The high wire growing regimes, as evaluated in this project, were not economically viable compared to the conventional cordon system currently used by the majority of growers in the UK.
- The economic returns were greater from the three crop high wire regime than the two crop alternative. However, an additional 19.7 cucumbers per m^2 would have been required from the three crop regime for it to match the conventional regime.
- The use of chemical pesticides was not reduced in the high wire regime. Fungicide use was broadly similar to the cordon cropping system but more applications of acaricides were required to control spider mites.

- It is recommended that the following technical issues be addressed before growers undertake any further large scale trials:
    - The cultivars which are currently available do not lend themselves to the high wire method of production. More specialised cultivars are required.
    - The published methods based on leaf area index did not provide a satisfactory means of managing plant vigour during the periods of very poor natural light and / or fluctuating weather conditions. Improved methods of managing plant vigour are required.
    - Biological control of spider mites with *Phytoseiulus persimilis* was not effective in the high wire crops. More rapid and effective control measures are required against spider mites.
- Labour costs remain one of the greatest obstacles to the uptake of the high wire growing system in the UK. High wire production requires 55-60% more labour input than conventional cordon production and this equates to approximately £2.2 per m^2 per season. This could probably be reduced by further investment in moveable crop wires and automated removal of redundant leaves.

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