# FINAL REPORT

To:
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Cucumber: A technical and economic evaluation of AYR production

March 2007

**Commercial – In Confidence**

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| Project Title: | Cucumber: A technical and economic evaluation of AYR production |
| Project number: | PC 201 |
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The results and conclusions in this report are based on a carefully monitored applied experiment in a large-scale experimental glasshouse. The conditions under which the studies were carried out and the results 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 the 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 my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

Signature……………………………………………………………………………

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# GROWER SUMMARY

## Headline

The need to satisfy the demand for an interrupted supply of cucumbers initiated the investigation of AYR production in which nine cucumber crops (cv Aviance) were grown in sequence using supplementary lighting over three production years (October 2003 - November 2006) with substantial yield increases demonstrated compared to best conventional practice. However, the increased energy demand from producing an AYR crop makes this approach viable only when energy prices allow and a simple spreadsheet has been devised for growers to calculate this for their own businesses.

## Background and expected deliverables

In 2001, the Cucumber Growers' Association (CGA) recognised that the UK cucumber industry must attempt to satisfy the increasing demand for uninterrupted supplies of good quality, traceable produce grown using pest and disease management practices that eliminate chemical residues. To do this, the industry first had to establish how to grow all year round crops (AYR) efficiently, which was the basis of this project. However, this was not to be at any cost.

The overall aim of the project was to maximise annual cucumber production per units of energy and other resources used. The approach was to evaluate new technologies and growing systems that were becoming available in northern Europe. Most of these new technologies had been developed independently for other crops and it was important to determine how they could be modified and integrated to benefit cucumber production under UK conditions. The experimental facility included the following package of essential complementary equipment:
Supplementary lighting at a single intensity (10,000 lux) throughout the unit.
Energy screens of a single design throughout the unit.
An advanced environmental control system.
Raised gutter system
The project did not attempt to isolate the individual benefits of the component technologies because they were all integral parts of the whole package.

The CGA nominated Stockbridge Technology Centre Ltd (STC) to be the principal contractor with overall responsibility for the co-ordination of financial and practical aspects of the project. However, the project was overseen by a management team, which was appointed by the CGA Committee. In addition, the team drew on the expertise of representatives from the broader range of partners / contributors to the project. This included: BCP Ltd, Cavegates Nursery, CGA Technical Committee, CMW, Ecotech, EVS, Glen Avon Growers, Green Meteor, Grodan UK, Hedon Salads, HDC, Hortilux Schreder, Priva, Leen Huisman, Ludvig Svensson, Marks and Spencer, Melrow Salads, Rijk Zwaan, Plant Raisers Ltd, Syngenta Bioline.

The project operated on the basis of continuous Knowledge and Technology Transfer. Data was collated regularly and made available to CGA and HDC members for comparison with production and energy use in their own glasshouses.

## Summary of the work completed to date

Key Points:

- This project has provided clear guidance on the agronomic approach to AYR cucumber production in the UK.
- A sequence of nine crops (cv Aviance) were grown using supplementary lighting over three production years between October 2003 and November 2006.
- During the first 12 months, the three crops yielded a total of 314 cucumbers per m2, compared to the national average for conventionally grown crops of 120-125 cucumbers per m2.
- The objective in the second and third years was to retain yield while determining by how much the energy inputs could be reduced.
- Production in the second year was down by approximately 5% but quality was maintained. However, the commercial growers who provided the comparison with best conventional practice also produced less (approximately 12% down on 2003/04). The specific energy consumption per cucumber for a CHP-based AYR facility was calculated to be 4.11 kWh/m2/cucumber in 2004/05; i.e. 14% lower than a conventional crop.
- The overall production for the third year was down by approximately 9% compared to the first year. There is little doubt that the stringent energy saving practices in the final crop resulted in a deterioration in plant health, yield and fruit quality compared to previous years.
- There were found to be considerable benefits from growing cucumbers by the high wire system under this environmental regime. The system will now be evaluated without supplementary lighting to determine whether it will still provide benefits without the large investment required for the whole AYR system.
- A subsidiary project analysed the use of labour in cucumber production and was submitted as an appendix to the main report.
- The financial viability of AYR production changed as energy prices increased during the project. At the end of the first year, the financial surplus for AYR crops grown with CHP was £98.5k / ha greater than conventional production. Despite the adoption of successful energy saving practices, this margin was eroded in the second year and virtually eliminated in the third year as energy costs soared. However, it is important to note that energy prices have since fallen and the scenario has improved.

- A single economic evaluation of AYR production will never be applicable to all growers due to the variations in facilities and output. However, a spreadsheet has been produced that will take many of these variables into account and this could be used to produce personal predictions for individual growers. The spreadsheet will be made available to levy payers later in 2007 as part of an HDC Factsheet that will summarise the key findings of this project.
- In practice, the final decision on whether to adopt AYR production technology will probably be driven by the demands of the retail customer and their willingness to pay prices that truly reflect the cost of producing such a high quality product.

Establishment of experimental facility

The experimental facility at STC was a Wilco High Light Double Venlo glasshouse of just under 1000m$^2$ floor area. The height to gutter and top of the ridge being 4.0m and 4.7m respectively.

As the prime motivation for the project was to test the technical and economic viability for all year round production, supplementary lighting was one of the key equipment requirements for the project. Based on the work carried out in a previous feasibility study (see report for HDC project PC 193) lighting equipment was installed to deliver a minimum maintained lighting level of 24W/m$^2$ PAR (10,000lux with high-pressure sodium lamps). This was achieved using 136 Hortilux HS-Remote 400 Volt / 600 Watt lamp and luminaire units. These units were of the 'remote ballast' design. This design is based on mounting the lamp and reflector assembly at high level above the crop, with the operating gear being contained in a separate housing, which is mounted at a low level. Developments in lighting technology mean it is likely that any new installation would use electronic operating gear. In this case all the equipment would be mounted above the crop.

To optimise energy savings and provide the best opportunities for climate control, screens were installed in the facility. Non voided Ludvig Svennson SLS 10 Ultra Plus material was used over the entire growing area. This fabric was chosen on the basis of its energy saving performance, diffuse light transmission, vapour transmission and pack size when drawn back (i.e. open). All of these factors combined to achieve overall performance that was considered to be most beneficial to crop development whilst giving energy savings.

A Priva Integro control system was used to control and monitor the environment in the glasshouse and the crop irrigation system. Control extended to all environment systems including heating, lighting, screens, ventilation and CO2 enrichment. This system had the functionality to provide temperature integration based control strategies. In addition, predictive weather forecasting could be provided via Priva's MeteoVision system. Both of these capabilities could be used to optimise the energy performance of the facility.

Raised troughs were installed in half of the growing area of the glasshouse (i.e western side of the central service path). The equipment used was the GreenMeteor rolled steel system. Each gutter was supported by a combination of 2 trellis hooks and 3 floor supports per gutter.

Agronomic summary

There were nine sequential crops (cv Aviance), which were planted in the production house in week 45 2003, weeks 9, 26 and 44 2004, weeks 10, 29 and 45 2005, and weeks 9 and 27 2006.

In the first production year, all crops received 10,000 lux of supplementary lighting for up to 18 hours per day with the illuminated period ending one hour before sunset. The plants were grown using the high wire (or layered) system. This involved training a single stem up a vertical string to a horizontal support wire positioned 3.6m above ground. As the plant approached the wire, it was layered so that only the most recent 2.7 - 3.3m of growth was ever vertical. Side shoots and lower leaves were removed once or twice per week. This system was chosen because the younger and most productive leaves were positioned to maximise light interception. The crops were established at 23°C during the illuminated / natural day period and at 21°C during the dark period, which produced the rapid stem extension needed in the early stages of the crop. Once fruit had developed and crop vigour was reduced, the night temperature was dropped to 15-16°C to maintain the required growth and fruit set. This regime gave the combination of high day temperatures and cool pre-nights that is required to optimise growth, vigour and fruit length (the latter being an important consideration with cv Aviance). The plants began to produce fruit 21 days after being transferred to the glasshouse. Crops 1, 2 and 3 had a combined yield of 314.36 cucumbers per $m^2$. This compared very favourably to the national average for conventionally grown crops (i.e. 120-125 cucumbers per $m^2$) and best conventional production in 2004 (i.e. 153 cucumbers per $m^2$). There was very little difference between the productivity of the plants mounted on the raised gutters and those on the floor.

The main objective in the second production year was to reduce energy inputs without having a detrimental effect on yield. The principal changes to the growing regime were:

- Plant density was increased from 2 to 2.5 plants per $m^2$ in the winter crop (crop 4).
- The day length was initially extended from 18 to 19 hours.
- Daylength was not artificially extended during the summer period.
- Ventilation was restricted to reduce energy losses and to retain the released carbon dioxide.

- The minimum pipe temperature was run much lower than in a conventional crop.

Although we had some control over the amount of radiant energy the crop received, one of the major factors in production volume is natural radiation. In 2004, the natural radiation (measured as light levels) was actually 3% higher than the 20 year average, but was 9% down on the previous very good year. The overall figure for 2005 was almost identical to 2004 but the figures were much more variable in 2005, with some very good weeks followed by very bad weeks. For example, the planting week for the third crop (week 30) was particularly bad, with less than 60% of average radiation for that week.

The overall production for the 2004/05 season was down by approximately 5% compared to the previous year, with a total of 297 cucumbers/$m^2$. However, the commercial growers who provided the comparison with best conventional practice were down by approximately 12% compared to the previous year. We must therefore take into account a seasonal effect, which was probably largely due to the variable light levels.

Compared to the previous winter crop (crop 1), supplementary lighting was increased by extending the lit period from 18 to 19 hours per day. If we include the hour before sunset without lights, which was given to allow the plants to keep their circadian rhythm aligned to solar time, then the total lit period was 20 hours. The aim of this long day was to produce more fruit from the higher density of plants but it appeared to have the opposite effect. In fact, the average weekly production fell from 5.63 cucumbers/$m^2$ in the first production year to 5.57 cucumbers/$m^2$ in the second year. Furthermore, fruit size and quality were also poorer in crop 4 than in crop 1. It was clear that the lowest fruits were growing more slowly than the ones immediately above and they were struggling to reach the desired weight of >350g. Following discussions with Scandinavian research workers, it was thought that the short night (only four hours) may be insufficient to allow to the plants to complete their dark period functions. In particular, there could have been insufficient time for the transfer of assimilates, accumulated during the light period, to the developing fruits lower down the stem. In summary, it is assumed that the longer day, and associated problems with fruit development negated any benefits of the higher plant density used in crop 4 and reduced production in the early stages of crop 5.

As a means of reducing the labour input to the high wire crop, two novel clipping systems were tested on a limited number of crop rows during the second production year; i.e. the 'Qlipr' system developed by Cor Pelikaan and a simple plastic clip supplied by Brinkman. Both systems used a thin metal rod suspended from the crop wire to carry the clips that support the stem. The Brinkman stem clip system was dropped at a very early stage because it failed to support the plants sufficiently well. The Qlipr stem clip system was more successful in supporting the plants and became increasingly popular with crop workers as the project progressed.

The main objective of the third production year was to reduce the energy inputs compared to the second year while minimising the impact on yield. The principal change to the growing regime was that supplementary lighting was reduced to 17 hours, thus saving one hour of lighting per day. The end of the lighting period was changed from one hour to 0.5 hour before sunset, so that the plants' day now began 17.5 hours before sunset. As natural light levels increased with extending natural day length, the lights were switched off at 300 $W/m^2$ and programmed to come back on as light levels dropped in the afternoon unless the total sum of natural light plus supplementary light already exceeded 2000 $J/cm^2$ that day. The lights were switched off completely between mid-June and early September. In line with the overall strategy, ventilation was restricted to reduce energy loss and to retain carbon dioxide levels.

It is important to gauge the performance of the crops in the third production year relative to best conventional practice so that any seasonal effects can be taken into account. Following a drop in production due to poor light levels in 2004/05, conventional growers' yields in 2005/06 returned to the levels achieved in 2003/04. It is therefore most appropriate to draw comparisons between the first and third years.

Yields for the AYR crops in the third production year were down by 9.1% compared to year one. This was attributed to the stringent energy saving regime, which successfully reduced the quantity of energy used per cucumber by 9.6% compared to year one but created conditions that were favourable for the establishment of stem diseases. Most of this yield reduction occurred in the final crop (i.e. crop 9). The energy saving strategy for the first two crops of year 3 should therefore be considered successful, while further modifications are required for the third crop.

With hindsight, there is little doubt that the disease incidence in the final crop could have been reduced by more timely and intensive applications of fungicides prior to the first harvest. However, this would not have been consistent with the CGA's overall policy of reducing pesticide use. It is probable that the situation could have been improved by using more pipe heat in the early stages of the crop although this would have sacrificed a proportion of the energy savings. A similar effect could have been achieved more efficiently with a grow pipe had one been available. These factors should all be taken into account in the future.

Many of our findings were consistent over the three production years. The plants grew at the approximate rate of 0.6m per week and when the growing points were removed the stems were 9-11m long depending on the time of year. Although production in the second and third project years was not quite as predictable as the first year, it was still very consistent compared to conventional cordon crops where "flushing" is the norm. This consistency and regularity would be extremely useful to growers in predicting output and coping with market demands.

The high wire system was originally chosen because the younger and most productive leaves are positioned to maximise light interception. With the cordon system, these leaves are shaded by the older growth around the support wire and it was thought that this would restrict yield. The latter was proven to be correct in two commercial cordon crops which received supplementary illumination during 2003/04. Other anticipated advantages of the high wire system that proved to be correct were:

- Improved light penetration to the fruit giving better fruit colour.
- Good air circulation, aiding disease suppression.
- Easier and faster fruit picking because the mature fruit are all in the same position; i.e. at the base of the vertical portion of the plant on the otherwise bare stem, thereby providing the potential to save labour.
- The growth of the plant and fruit production is clearly sequential, which simplifies evaluation of performance and crop management decisions.
- Frequent leaf removal is believed to contribute to the suppression of establishment of foliar pests and diseases.
- The high wire system will be evaluated without supplementary lighting (HDC Project PC 273) as this could provide considerable benefits to growers without the large investment required for the whole AYR system.

Labour inputs

The main labour consideration in this project was to compare the requirement of high wire and conventional cordon-trained crops. The tasks and labour input are similar until the plants reach the support wire but thereafter become very different. In a cordon crop, most of the labour is then devoted to finding and picking fruit that are in random positions within the proliferation of foliage. By contrast, in the high wire system, only a small proportion of time is devoted to picking because the location of the fruit is predictable and they are easily accessible. Instead, the majority of the labour is required to remove side shoots and unwanted fruit, twist new growth into the support strings, remove old leaves and layer the plants. It was known from best commercial practice that cordon crops required about two crop workers per 5000m$^2$. However, it proved difficult to determine such a figure in the experimental high wire system because the relatively short row length led to a disproportionate amount of dead time; eg moving trolleys between rows. It was also difficult to look at crop training and harvesting in isolation because they were influenced by many other factors. As the experimental high wire facility gave an unrealistic impression of labour use, it was decided to undertake a separate desk study to analyse labour input in different types of commercial production units in the UK and Netherlands. This study was completed by Derek Hargreaves and is presented as a “stand-alone” report in Appendix 1.

Summary of energy inputs

The energy saving practices employed in the second and third production years by i) reducing pipe heat and venting for humidity control, and ii) reducing supplementary lighting during the summer were extremely successful. The total quantities of energy used as hot water and electricity in the 52 weeks up to week 44 2005 were 444 and 470 kWh/$m^2$ respectively. These represented reductions of 16% and 14% respectively compared to the first 52 week period. There were further improvements in the 52 weeks up to week 44 2006 when the total quantities of energy used as hot water and electricity were 430 and 431 kWh/$m^2$, representing reductions of 19% and 21% compared to the first 52 week period.

From an energy use perspective, the specific energy consumption per cucumber (SEC) produced is a useful figure because it also takes into account fluctuations in yield. In 2004/05, the SEC for an AYR crop using boiler heat and mains electricity for lighting was calculated to be 6.37 kWh/$m^2$/cucumber, i.e. 33% higher than a conventional crop. However, if CHP were used, the SEC would be reduced to 4.11 kWh/$m^2$/cucumber, i.e. 14% lower than a conventional crop using boiler heat and mains electricity. A similar calculation for 2005/06 showed the SEC for an AYR CHP-based system to be 6% less than a conventional crop using boiler heat and mains electricity. The drop from 14% to 6% differential over that period illustrated the progress being made by conventional growers with energy conservation techniques.

## Financial benefits to growers

The main driving force behind this project was to satisfy the increasing demand from retailers for uninterrupted supplies of good quality, traceable produce grown using pest and disease management practices that eliminated chemical residues. If achieved, this should have led to an increased market share through import substitution.

A preliminary economic evaluation after the first production year showed the financial surplus for AYR crops grown with boiler / mains electricity and for AYR crops grown with CHP to be £66.4k and £98.5k / ha greater respectively than conventional production.

Significant savings were made in energy use in the AYR facility in the second year and the financial surplus compared to conventional production should have improved. However, energy prices increased substantially during that year; gas and electricity prices were taken as 1.3 and 3.8 p/kWh respectively for 2003/04, and 1.5 and 4.5 p/kWh respectively for 2004/05. These increases masked the benefits of some of the savings through greater efficiency.

Yields were down in both conventional crops and the AYR crop in 2004/05. When all factors were taken into account, the surplus for AYR crops with boiler / mains electricity and for AYR crops with CHP would have been £45.4k and £79.3k per hectare greater respectively than conventional production. This would still have been economically viable for growers who had the necessary equipment in place but it was clearly becoming a less attractive option for those who were considering making an investment in a new AYR facility.

Energy prices continued to rapidly rise during 2005/06 and yields were down in the final crop as an indirect consequence of the stringent energy saving regime. When all these factors were taken into account, the financial returns from AYR production with CHP were similar to conventional production and the initial investment in AYR production could no longer be justified. However, it is important to note that this scenario had once again changed at the time of completing this report (March 2007) because energy prices had fallen significantly.

## Action points for growers

- This project has provided clear guidance on the agronomic approach to AYR cucumber production in the UK.

- The financial viability of AYR production changed as energy prices increased during the project. At the end of the first year, the financial surplus for AYR crops grown with CHP was £98.5k greater / ha greater than conventional production. Despite the adoption of successful energy saving practices, this margin was eroded in the second year and virtually eliminated in the third year as energy costs soared. However, it is important to note that energy prices have since fallen and the scenario has improved.

- In the future, it may be appropriate to consider variations on AYR production. For example, yields are relatively low in early winter (even with supplementary lights) and the price of produce is kept low by imports from Spain, so it may prove sensible to delay planting until December and then use lights to boost early season production.

- In practice, the final decision on whether to adopt AYR production technology will probably be driven by the demands of the retail customer and their willingness to pay prices that truly reflect the cost of producing such a high quality product.

- A single economic evaluation of AYR production will never be applicable to all growers due to the variations in facilities and output. However, a spreadsheet has been produced that will take many of these variables into account and this could be used to produce personal predictions for individual growers. The spreadsheet will be made available to levy payers later in 2007 as part of an HDC Factsheet that will summarise the key findings of this project.

# SCIENCE SECTION

## PART 1: GENERAL INTRODUCTION

In 2001, the Cucumber Growers' Association (CGA) recognised that the UK cucumber industry must satisfy the increasing demand for uninterrupted supplies of good quality, traceable produce grown using pest and disease management practices that eliminate chemical residues. To do this, the industry first had to establish how to grow all year round crops (AYR) efficiently, which was the basis of this project. However, this was not to be at any cost.

The need for this study was originally identified by the CGA membership at the 2001 Technical Conference / AGM. Responsibility for determining the feasibility of the venture was delegated to a group of CGA members with complementary specialist skills. This organising group (OG) found a suitable site for an experimental glasshouse unit and liaised with ten manufacturers / suppliers to form a consortium of partners who were prepared to provide "in-kind" support in the form of equipment and expertise. A formal feasibility study (jointly commissioned by the CGA and HDC) was completed in July 2002, which demonstrated that the venture was technically and economically viable (Jacobson, Hargreaves & Plackett, 2002). The OG was subsequently unsuccessful in obtaining financial support from DEFRA and restructured their proposal. In the alternative financial plan, the consortium of partners and contractors took responsibility for all capital expenditure, while running costs of the experimental unit were provided through the HDC and from the sale of produce. The CGA nominated Stockbridge Technology Centre Ltd (STC) to be the principal contractor with overall responsibility for the co-ordination of financial and practical aspects of the project. The project was overseen by a management group, appointed by the CGA Committees and consisting of key individuals from the consortium of partners.

The Project Management team comprised:

- Project Co-ordinator – Robert Bezemer – Initially CGA Chairman, from 2004 CGA Committee member
- Project Leader – Initially Rob Jacobson as an STC employee, from May 2006 Graham Ward, STC Ltd
- Project Administrator - Rob Jacobson, Horticultural Consultant & CGA Secretary
- Agronomist – Derek Hargreaves, Horticultural Consultant & CGA Technical Officer
- Equipment consultant – Chris Plackett, FEC Services
- Environmental control consultant – Tim Pratt, FEC Services
- Grower – Paul Dudley, STC Ltd

In addition, the team drew on the expertise of representatives from the broader range of partners / contributors to the project. This included: BCP Ltd, Cavegates Nursery,

CGA Technical Committee, CMW, Ecotech, EVS, Glean Avon Growers, Green Meteor, Grodan UK, Hedon Salads, HDC, Hortilux Schreder, Priva, Leen Huisman, Ludvig Svensson, Marks and Spencer, Melrow Salads, Rijk Zwaan, Plant Raisers Ltd, Syngenta Bioline.

## Overall aim and objectives

The overall aim of the project was to maximise annual cucumber production per units of energy and other resources used. The approach was to evaluate new technologies and growing systems that were becoming available in northern Europe. Most of these new technologies had been developed independently for other crops and it was important to determine how they could be modified and integrated to benefit cucumber production under UK conditions. The experimental facility included the following package of essential complementary equipment:

- Supplementary lighting at a single intensity (10,000 lux) throughout the unit.
- Energy screens of a single design throughout the unit.
- An advanced environmental control system.
- Raised gutter system

The project did not attempt to isolate the individual benefits of the component technologies because they were all integral parts of the whole package.

**The specific objectives were**:

1. To establish a facility for the industry that was suitable for the evaluation of AYR cucumber production.
2. To quantify output from an AYR cucumber production unit in the UK.
3. To quantify inputs required to achieve Objective 2.
4. To compile and collate comparative data from current commercial "best practice".
5. To optimise economic margins for AYR cucumber production.
6. To transfer new knowledge and technology to cucumber growers.
7. To provide direction for complementary studies.

Comparisons were drawn with best current conventional practice using records collected by commercial nurseries.

## Modifications agreed at Project Review Meetings:

The following actions were agreed at the Project Review Meeting on 22 September 2004 and were implemented for crops 4, 5 and 6:

- **Overall strategy:** The second production year of the project would focus on reducing energy inputs.
- **Number and duration of crops:** There would be three crops over 52 weeks (as opposed to 50 weeks in the first year). The first and second crops being extended in length and the third reduced following experience in the first year.
- **Plant density:** Plant density would be increased in crop 1 (ie to 2.5 plants per $m^2$), remain the same in crop 2 (ie 3 plants per $m^2$), and be reduced during crop 3 (ie starting at 3 plants per $m^2$ but reducing to 2.5 plants per $m^2$ as the crop enters the autumn).

- **Lighting:** The photoperiod would be increased to 19 hours per day with supplementary lighting used below thresholds of 300, 150 and 250W/m$^2$ for crops 1, 2 and 3 respectively.
- **Screens:** The strategy would not change.
- **Cultivars:** Aviance to remain the main cultivar, although small areas of other mildew resistant cultivars, which were considered suitable for production under supplementary lights, were to be evaluated.
- **Temperature integration:** This would not be used because the high day / low night temperature regime offered little opportunity to make use of this facility.
- **$CO_2$ Strategy**: $CO_2$ use would be more closely aligned to energy inputs.
- **Measuring equipment**: An extra aspirated screen would be installed to allow comparison of environmental measurements at different positions in the crop. Grodan offered to supply a new version of their Moisture Content meter. The drain water measurement equipment would be further refined. All work would be contracted to CMW and completed as soon as possible.
- **Other equipment:** New stem supports, which raised the level of the horizontal stems, would be manufactured and installed for crop 4.
- **Labour:** Derek Hargreaves would undertake a desk study of labour use in conventional and high wire crops, drawing on information from the Netherlands. A new hydraulic scissor lift would be purchased to improve labour efficiency. The Brinkman and Pelikaan stem clip systems would be evaluated.
- **Funding:** HDC would consider bringing funds forward from the final year of the project to cover additional expenditure related to the above changes in year 2.

The following actions were agreed at the Project Review Meeting on 16 October 2005 and were implemented for crops 7, 8 and 9:

- **Overall strategy:** The objective in the third production year would be to get closer to the first year yield while further reducing energy use.
- **Plant density:** As in the second year, except crop 3 to be 2.5 plants per m$^2$ throughout.
- **Lighting:** Crop 1 - 18 hours per day; crop 2 - to start at 17 hours per day, reduced to 16 hours a light sum of 2000 J/cm$^2$, crop 3 - to start as crop 2 and revert to 17 hours per day from week from week 18 with supplementary light provided below thresholds of 150/Wm$^2$ up to 36.
- **Cultivars:** Aviance to remain the only cultivar.
- **Labour:** The use of the Pelikaan stem clip systems would be extended to half the glasshouse.
- **Funding:** HDC to adjust the final year budget to take into account funds brought forward to cover additional expenditure in year 2.

# PART 2: THE FACILITY

## 2.1. The glasshouse:

The chosen unit (coded M18 at STC Ltd) was a Wilco High Light Double Venlo glasshouse. Specifications included:

- 896m$^2$ floor area (909m$^2$ over dwarf walls)
- 25.6m wide by 35m long
- 4 double Venlo bays with 6.4m trellis orientated east-west
- Central 3m wide concrete road running north- south.
- Usable growing area - 820m$^2$
- The height to the gutter was 4.0m and to the top of ridge was 4.7m.
- Boal narrow profile box section aluminium gutters.
- Roof glazing in 1.0m wide glass
- Twin rubber glass seals
- 64 half pane ventilators, fitted for independent control on both sides of the ridge in staggered formation, giving 23.4% ventilation over floor area. All ventilators fitted with rubber seals.

## 2.2. The equipment

### *Background*

The equipment installed in the glasshouse facility was designed and selected to achieve the following:

- The economic production of cucumbers on an all year round basis
- Provision of the optimum environment for crop production
- Energy savings in order that energy costs are acceptable and energy performance targets can be achieved.
- A demonstration of 'state of the art' commercially available equipment.

### *Lighting*

As the prime motivation for the project was to test the technical and economic viability for all year round production, supplementary lighting was one of the key equipment requirements for the project.

Based on the work carried out in the feasibility study (Jacobson, Hargreaves & Plackett, 2002), lighting equipment was installed to deliver a minimum maintained lighting level of 24W/m$^2$ PAR (10,000lux with high-pressure sodium lamps) after 1000hrs of operation. This was achieved using 136 Hortilux HS-Remote 400 Volt / 600 Watt lamp and luminaire units. These units were of the 'remote ballast' design (*i.e.* lamp and reflector assembly mounted at high level above the crop with the operating gear being contained in a separate housing mounted at a low level). The advantages claimed for this design were:

- The dimensions of the lamp and reflector assembly were kept to a minimum, thus keeping natural light disturbance to a minimum.
- The heat dissipated by the operating gear was positioned at the base of the crop.
- The use of a 400 volt 3 phase lamp eliminated potential problems with third harmonic disturbance.

Lamps were arranged in 17 rows of 8 lamps per row (4 each side of the central path). The lamps and reflectors were suspended in a staggered formation to provide optimum distribution of light.

Developments in lighting technology by 2006 mean it is likely that any new installation would use electronic operating gear. In this case all the equipment would be mounted above the crop.

### *Screens*

To optimise energy savings and provide the best opportunities for climate control, screens were installed in the facility. Non voided Ludvig Svennson SLS 10 Ultra Plus material was used over the entire growing area. This fabric was chosen on the basis of its energy saving performance, diffuse light transmission, vapour transmission and pack size when drawn back (*i.e.* open). All of these factors combined to achieve overall performance that was considered to be most beneficial to crop development whilst giving energy savings.

The screen installation was equipped with a slipping clutch system. This simplified the opening / closing mechanism and ensured that the reliability of screen operation was maintained throughout the life of the installation.

To minimise sidewall and edge effects, side screens were also installed. This minimised heat losses from the sidewalls and helped to ensure that an even climate was achieved throughout the facility. Ludvig Svennson SLS10 Ultra plus material was used on one side (west facing wall) of the facility. On the other three sides a material that did not allow light transmission (Ludvig Svennson XLS Obscura w/w) was installed to avoid light spill to neighbouring greenhouses.

It should be noted that the experimental nature of the facility caused a number of problems with the screen installation. These included:

1. The configuration of glasshouse structural members did not allow the use of an extruded profile leading edge that would be used on a similar commercial facility. This lead to the screen not closing as tightly as might be expected on an equivalent commercial glasshouse. Also pack size of the retracted screen was not as small as might be expected in commercial practice.

2. Glasshouse structural members also meant that some portions of fixed pelmet had to be installed to achieve full screen coverage and acceptable sealing. Again this approach should not be necessary on a commercial facility.
3. The side screens could not be positioned in the optimum position between the stanchions and the glazing. The effect of this was that the side screens intruded into the house further than on an equivalent commercial facility and caught the leaves of the outer row of plants as they rolled upwards. This restricted automated use of the side screens to the first 2-3 weeks of each crop. Thereafter, in the winter crops (*i.e*. crops 1, 4 and 7), the southern wall screens remained permanently open while those on the other three walls were permanently drawn. All side wall screens were permanently open in crops 2, 3, 5, 6, 8 and 9. Sealing at the corners of the house was also not as good as might be desired.

***Raised Troughs***

Raised troughs were installed in half of the growing area of the glasshouse (*i.e* western side of the central service path). The equipment used was the GreenMeteor rolled steel system. Each gutter was supported by a combination of 2 trellis hooks and 3 floor supports per gutter. This approach had to be taken because it was unclear whether the glasshouse structure would fully support the loads imposed by the gutter system.

Units were installed to allow the collection of irrigation water run-off for analysis and / or recycling should that have become necessary.

***Environmental Control System***

A Priva Integro (v721) control system was used to control and monitor the environment in the glasshouse and the crop irrigation system. Control extended to all environment systems including heating, lighting, screens, ventilation and $CO_2$ enrichment. The system was upgraded regularly during the project, with the final version being the Integro v724.

This system had the capability to provide temperature integration based control strategies. In addition, predictive weather forecasting was provided via Priva's MeteoVision system. Both of these capabilities could be used to optimise the energy performance of the facility.

Energy monitoring inputs were also connected to the Priva computer. This included a heat meter that was used to accurately monitor the amount of heat supplied to the house. Electricity use was monitored through a dedicated meter.

# PART 3: SUMMARY OF WORK IN FIRST TWO PRODUCTION YEARS

## 3.1. The facility

The facility to evaluate AYR cucumber production was successfully established as described in Part 2 of this report. During the course of the first production year, the monitoring equipment was upgraded to improve the management of the irrigation system; *i.e.* measurements of drain water and moisture content of slabs via Grow scales. Additional equipment was installed during the second production year to further improve the measurement of the aerial environment, $CO_2$ usage and drainage, as well as to improve labour efficiency (see Part 1 of this report).

## 3.2. Crop diaries

All crops were cv Aviance raised by Plant Raisers Ltd.

***Crop 1***

- Sown 8 Oct 2003 (wk 41) and transferred to production house 6 Nov 2003 (wk 45)
- Cucumber harvest began on 27 November 2003 (wk 48)
- Plants stopped by removing main growing point on 11 February 2004 (wk 7)
- Crop terminated 24 February 2004 (wk 9)

***Crop 2***

- Sown 31 Jan 2004 (wk 4) and transferred to production house 26 Feb 2003 (wk 9)
- Cucumber harvest began on 18 March 2004 (wk 12)
- Plants stopped by removing main growing point on 28 May 2004 (wk 22)
- Crop terminated 15 June 2004 (wk 25)

***Crop 3***

- Sown 31 May 2004 (wk 23) and transferred to production house 26 June 2004 (wk 26)
- Cucumber harvest began on 15 July 2004 (wk 29).
- Plants stopped by removing main growing point on 1-4 October 2004 (wk 40)
- Crop terminated 19 October 2004 (wk 43)

***Crop 4***

- Sown 29 Sept 2004 (wk 40) and transferred to production house 28 Oct 2004 (wk 44)
- Cucumber harvest began on 24 November 2004 (week 48)
- Plants stopped by removing main growing point on 18 February 2005 (week 7)
- Crop terminated 7 March 2005 (week 10)

***Crop 5***

- Sown 11 Feb 2005 (wk 6) and transferred to production house 10 Mar 2005 (wk 10)
- Cucumber harvest began on 31 March 2005 (week 13)
- Plants stopped by removing main growing point on 4 July 2005 (week 27)

- Crop terminated 13 July 2005 (week 28)

***Crop 6***

- Sown on 26 Jun 2005 (wk 25) and transferred to production house 19 July 2005 (wk 29)
- Cucumber harvest began on 9 August 2005 (wk 32).
- Plants stopped by removing main growing point on 13 October 2005 (wk 41)
- Crop terminated 28 October 2005 (wk 43)

### 3.3. Summary for first full production year

***Agronomic summary***

There were a total of three sequential crops (cv Aviance - Rijk Zwaan), which were planted in the production house in week 45 of 2003, week 9 of 2004 and week 26 of 2004. Each crop was of 16-17 weeks duration. All crops received 10,000 lux of supplementary lighting for 18 hours per day. The illuminated period always ended one hour before sunset, thus providing the plants with an "environmental signal" to keep their circadian rhythm aligned to solar time.

The plants were propagated in Grodan rockwool blocks by Plant Raisers Ltd and grown on Grodan Master rockwool slabs (20cm x 7 cm x 1.2m), which were either mounted on raised gutters or positioned on the floor.

The plants were grown using the high wire (or layered) system, which was chosen because the younger and most productive leaves were positioned to maximise light interception. This involved training a single stem up a vertical string to a horizontal support wire positioned 3.6m above ground. As the plant approached the wire, it was layered so that only the most recent 2.7-3.3m of growth was ever vertical. Standard tomato layering hooks were used to keep control of the stems. Side shoots and lower leaves were 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 lateral shoots are then allowed to cascade downwards to a length of approximately 1m. 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.

The fruit were thinned to one at every other leaf, which simplified this aspect of crop management. Lower leaves were removed as the stems were layered, maintaining approximately 18-19 leaves per stem and giving a density of 45-55 leaves per $m^2$. This strategy allowed more air to circulate around the horizontal stems with the aim of reducing disease incidence.

The crops were established at 23$^{o}$C during the illuminated / natural day period and at 21$^{o}$C during the dark period, which produced the rapid stem extension needed in the early stages of the crop. Once fruit had developed and crop vigour was reduced, the night temperature was dropped to 15-16$^{o}$C to maintain the required growth and fruit set. This regime gave the combination of high day temperatures and cool pre-nights that is required to optimise growth, vigour and fruit length (the latter being an important consideration with cv. Aviance). At first, there were difficulties in reducing temperature rapidly during the pre-night but these were resolved by improved manipulation of the screens.

The plants began to produce fruit 21 days after being transferred to the glasshouse. Crops 1, 2 and 3 yielded 73.15, 126.40 and 116.00 cucumbers per m$^2$ respectively, giving an overall total of 314.36 cucumbers per m$^2$ (Figure 2). This compared very favourably to the national average for conventionally grown crops (*i.e.* approximately 125 cucumbers per m$^2$) and best conventional production in 2004 (*i.e.* 153 cucumbers per m$^2$). There was very little difference between the productivity of the plants mounted on the raised gutters and those on the floor.

The fruit were graded, wrapped and packaged by Cavegate Nurseries and sold to Marks and Spencer through Melrow Salads or ASDA through English Village Salads. The target weight of each fruit was >350g for all crops. Fruit that were below this weight were sold to the wholesale market.

Production was quite consistent throughout each crop with yields averaging 5.65, 9.72 and 7.73 cucumbers per m$^2$ per week in crops 1, 2 and 3 respectively. Such steady production is rarely seen in conventional cordon crops where "flushing" is the norm. This will be extremely useful in predicting output and coping with market demands. Furthermore, the quality of the fruit was excellent throughout the duration of the first and second crops, and first half of the third crop. Less than 1% of the cucumbers that were allowed to develop on the plants were unmarketable. This is in stark contrast to conventional crops in which large proportions of fruit abort on the plant or become unmarketable due to various malformations. As the production period moved into the shorter days of autumn, the plant density in the third crop appeared to be too high, resulting in early senescence of lower leaves and some deterioration of fruit quality.

There were found to be considerable benefits from growing cucumbers by the high wire system under this environmental regime. These are detailed in section 4.7.

***Summary of energy inputs***

The total quantity of energy used was 511 kWh/m$^2$ of heat delivered as hot water and 524 kWh/m$^2$ of electricity. From an energy use perspective, the specific energy consumption per cucumber (SEC) produced is possibly a more useful figure. The SEC for a lit crop using boiler heat and mains electricity was calculated to be 6.55

kWh/m$^2$/cucumber, *i.e.* 55% higher than a conventional crop. If CHP were used, it reduced to 4.16 kWh/m$^2$, *i.e.* 2% lower than a conventional crop.

The lights ran almost continuously for 18 hours per day through winter and until week 8. The running hours then gradually reduced to an average of 12 hours per day during the summer months. It was considered that significant savings in electricity consumption could be made during the summer when daily light integrals are high. Yield could be expected to suffer as a consequence, but the economic result should still be positive as this would coincide with high levels of production from natural season crops and therefore lower prices. An added efficiency gain was considered to be that the 'waste' heat generated by the lights during the summer is usually vented off to the atmosphere and does not displace boiler heat as in the winter months. This was an area that was focussed upon in the second production year.

The screen was primarily used to optimise energy saving but it was also used to improve the climate control whenever possible. The intention was to allow as much natural light into the crop as possible. However, in the first few days after planting the first crop it remained closed to reduce stress on the young plants. This reduced the required pipe temperature and also reduced the humidity deficit (HD) allowing the crop to establish rapidly. Once the crop was established, the screen was allowed to open if the outside temperature was sufficiently high and global radiation reached 80 W/m$^2$. For crop 1, grown through the middle of winter 2003/04, the screens were closed for an average of 17.4 hours per day. The hours of operation dropped rapidly from week 10 onwards to the point at which it was not used at all between weeks 23 and 36. Over the 50 week period the thermal screen was closed for a total of 2,940 hours.

The use of the screen to help provide a more stable, less harsh and more easily controlled glasshouse environment was seen as a considerable asset over and above its use in energy saving.

### 3.4. Summary for second full production year

#### *Agronomic summary*

The main objective in the second production year was to reduce energy inputs without having a detrimental effect on yield. There were a total of three sequential crops (cv Aviance), which were planted in the production house in week 44 of 2004, week 10 of 2005 and week 29 of 2005.

Many agronomic factors were consistent with the first production year. The principal changes to the growing regime were:

- The duration of the first two crops was extended to 18 weeks and the third crop was reduced to 14 weeks.
- Plant density was increased from 2 to 2.5 plants per m$^2$ in the winter crop (crop 4).

- The day length was initially extended from 18 to 19 hours.
- Daylength was not artificially extended during the summer period.
- Ventilation was restricted to reduce energy losses and to retain the released carbon dioxide.
- The minimum pipe temperature was run much lower than in a conventional crop.
- The Brinkman and Pelikaan Qlipr stem clip systems were evaluated as a means of reducing labour input to the high wire crop.

In line with the overall strategy, ventilation was restricted to reduce energy loss and to retain carbon dioxide levels. The minimum pipe temperature was reduced to 25°C whenever the humidity deficit measured at the base of the crop was considered to be acceptable. However, there was a short period at the start of the natural day when a set point of 45°C was applied to reduce the risk of condensation on the fruit. In poor humidity conditions, the set point was only allowed to increase to a maximum of 50°C.

Although we had some control over the amount of radiant energy the crop received, one of the major factors in production volume is natural radiation. In 2004, the natural radiation (measured as light levels) was actually 3% higher than the 20 year average, but was 9% down on the previous very good year. The overall figure for 2005 was almost identical to 2004 but the figures were much more variable in 2005, with some very good weeks followed by very bad weeks. For example, the planting week for the third crop (week 30) was particularly bad, with less than 60% of average radiation for that week.

The overall production for the 2004/05 season was down by approximately 5% compared to the previous year, with a total of 297 cucumbers/m$^2$ (Figure 2). However, the commercial growers who provided the comparison with best conventional practice were down by approximately 12% compared to the previous year. We must therefore take into account a seasonal effect, which was probably largely due to the variable light levels.

Compared to the previous winter crop (crop 1), supplementary lighting was increased by extending the lit period from 18 to 19 hours per day. If we include the hour before sunset without lights, which was given to allow the plants to keep their circadian rhythm aligned to solar time, then the total lit period was 20 hours. The aim of this long day was to produce more fruit from the higher density of plants but it appeared to have the opposite effect. In fact, the average weekly production fell from 5.63 cucumbers/m$^2$ in the first production year to 5.57 cucumbers/m$^2$ in the second year. Furthermore, fruit size and quality were also poorer in crop 4 than in crop 1. It was clear that the lowest fruits were growing more slowly than the ones immediately above and they were struggling to reach the desired weight of >350g. Following discussions with Scandinavian research workers, it was thought that the short night (only four hours) may be insufficient to allow to the plants to complete their dark period functions. In particular, there could have been insufficient time for the transfer of assimilates, accumulated during the light period, to the developing fruits lower down the stem. In summary, it is assumed that the longer day, and associated problems with fruit development, negated any benefits of the higher plant density used in crop 4 and reduced production in the early stages of crop 5.

Many of our findings were consistent over the two production years. The plants grew at the approximate rate of 0.6m per week and when the growing points were removed the stems were 9 - 11m long depending on the time of year. Although production in the second year was not quite as predictable as the first year, it was still very consistent compared to conventional cordon crops where "flushing" is the norm. This consistency and regularity would be extremely useful to growers in predicting output and coping with market demands.

As a means of reducing the labour input to the high wire crop, two novel clipping systems were tested on a limited number of crop rows during the second production year; *i.e.* the "Qlipr" system developed by Cor Pelikaan and a simple plastic clip supplied by Brinkman. Both systems used a thin metal rod suspended from the crop wire to carry the clips that support the stem. The Brinkman stem clip system was dropped at a very early stage because it failed to support the plants sufficiently well and caused considerable damage to leaf petioles and leaf lamina. The Qlipr stem clip system was more successful in supporting the plants and its use was extended to half the glasshouse in the third production year.

***Summary of energy inputs***

The total quantity of energy used as hot water in the 52 weeks up to week 44 2005 was 444 kWh/m$^2$. The amount of electricity used during the same period was 470 kWh/m$^2$. These represented reductions of 16.1% and 13.6% respectively compared to the previous 52 week period. The savings were principally achieved by i) reduction in pipe heat and venting for humidity control, and ii) reduced use of supplementary lighting during the summer, particularly between weeks 24 and 35.

The specific energy consumption per cucumber (SEC) produced also takes into account fluctuations in yield. In 2004/05, the SEC for an AYR crop using boiler heat and mains electricity for lighting was calculated to be 6.37 kWh/m$^2$/cucumber, *i.e.* 33% higher than a conventional crop using boiler heat and mains electricity. However, if CHP were used, the SEC would be reduced to 4.11 kWh/m$^2$/cucumber, *i.e.* 14% lower than a conventional crop. This figure for the CHP-based system showed a further improvement on the SEC calculated in 2003/04, which reflected our success in reducing energy inputs.

# PART 4. SUMMARY FOR THE THIRD PRODUCTION YEAR

## 4.1. Crop diaries

***Crop 7***

- Sown 10 Oct 2005 (wk 41) and transferred to production house 8 Nov 2005 (wk 45)
- Cucumber harvest began on 30 November 2004 (wk 48)
- Plants stopped by removing main growing point on 13 February 2006 (wk 7)
- Crop terminated 27 February 2006 (wk 9)

***Crop 8***

- Sown 2 February 2006 (wk 5) and transfered to production house 2 Mar 2005 (wk 9)
- Cucumber harvest began on 24 March 2006 (wk 12)
- Plants stopped by removing main growing point on 12 June 2006 (wk 24)
- Crop terminated 3 July 2006 (wk 27)

***Crop 9***

- Sown on 14 June 2006 (wk 24) and transferred to production house 6 July 2006 (wk 27)
- Cucumber harvest began on 24 July 2006 (wk 30).
- Plants stopped by removing main growing point on 16 October 2006 (wk 42)
- Crop terminated 3 November 2006 (wk 44)

## 4.2. General strategies and light levels

The main objective of the third production year was to reduce the energy inputs compared to the second year while minimising the impact on yield. As in previous years, there were a total of three sequential crops (cv Aviance), which were planted in the production house in week 45 of 2005, week 9 of 2006 and week 27 of 2006. Many agronomic factors were consistent with the first two production years. The principal change to the growing regime was that supplementary lighting was reduced to 17 hours, thus saving one hour of lighting per day. The end of the lighting period was changed from one hour to 0.5 hour before sunset, so that the plants' day now began 17.5 hours before sunset.

Although light levels have varied quite dramatically week by week during the three years of the project, the annual totals have been quite similar:

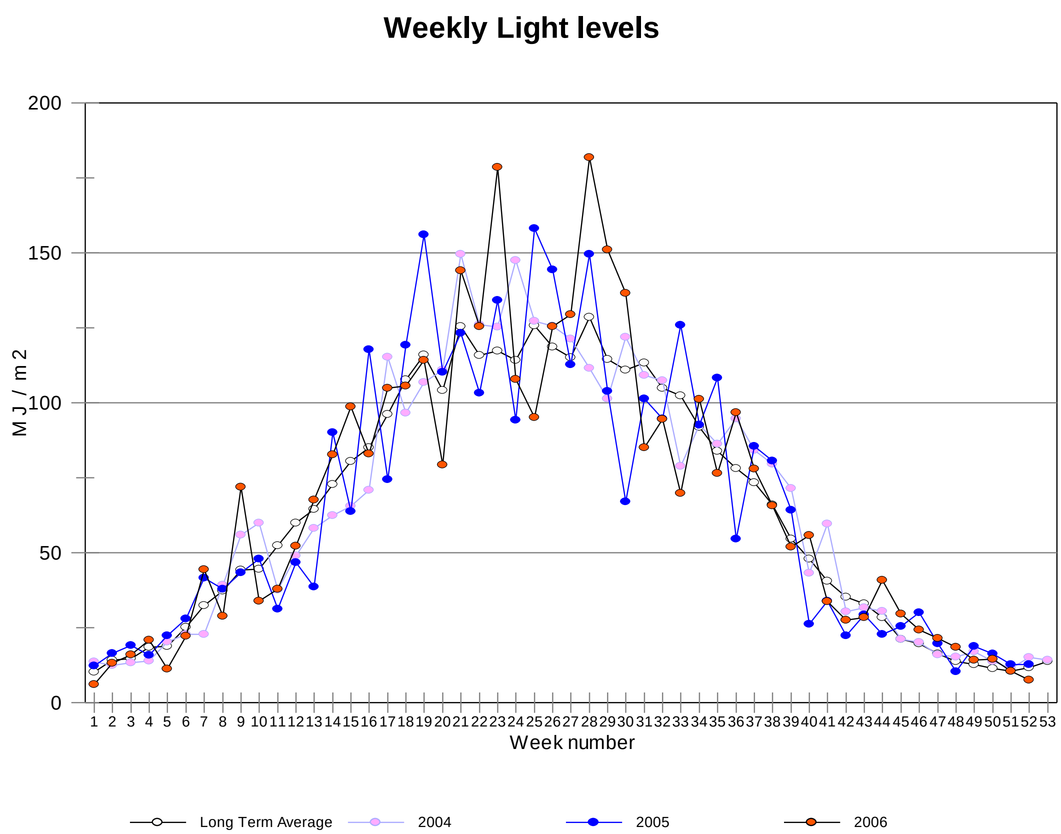
| | |
|---|---|
| 2004 | 3448 MJ / $m^2$ |
| 2005 | 3412 MJ / $m^2$ |
| 2006 | 3516 MJ / $m^2$ |
| 5 year average | 3520 MJ / $m^2$ |

20 year average 3370 MJ / $m^2$

Figure 1 shows each of the three years during the trial period and the long-term average. The 2006 total was very close to the 5 year average but was 4.3% up on the 20 year average. Figure 1 also shows the trend to higher light levels in the recent past, with the 5 year average being 4.5% up on the 20 year average.

**Figure 1. Comparative light levels in 2004, 2005, 2006 and the twenty year average (all expressed as weekly totals in MJ/m²)**




## 4.3. Crop 7: Specific strategies and production data

The winter crop of Aviance was planted on 8 November 2005 at a density of 2.5 plants per $m^2$. The environment was maintained at 20°C for two days to allow the plants to "settle in" and the thermal screens were kept permanently closed to keep the humidity deficit as low as possible. Keeping the screens closed reduced the heating pipe temperature, which assisted the rapid development of the plants.

Once the plants were established, the temperature was increased to 23°C day and 21°C during the dark period. This was maintained until just after the start of fruiting when a cooler "pre-night" (16°C) was added to allow the crop to maintain vigour and the required fruit size. To allow the temperature to drop on mild nights, the thermal screens were kept open until the glasshouse temperature had reached the required level. This maintained good plant vigour and helped reduce fruit length. Harvesting began 22 days after planting compared to 21 days in crop 1 and 27 days in crop 4. The longer interval from planting to cutting in crop 4 is believed to be due to the shorter dark period used at the start of that crop (see Section 3.4).

In line with the overall strategy, ventilation was restricted to reduce energy loss and to retain carbon dioxide levels. The minimum pipe temperature was reduced to 25°C whenever the humidity deficit measured at the base of the crop was considered to be acceptable. However, there was a short period at the start of the natural day when a set point of 45°C was applied to reduce the risk of condensation on the fruit. In poor humidity conditions, the set point was only allowed to increase to a maximum of 50°C.

The weekly output for crop 7, measured as marketable cucumbers/$m^2$, is compared to the previous two production years in Figure 2. The average weekly production fell from 5.63 cucumbers/$m^2$ in crop 1 to 5.57 cucumbers/$m^2$ in crop 4, which was attributed to the longer lit period (or more accurately the shorter dark period) at the start of that crop (see Section 3.4). The lit period in crop 7 was reduced compared to crop 1 and production fell further to 5.12 cucumbers/$m^2$. This indicates that the optimum lit period for cucumber production is about 18 hours per day; although the optimum day length in terms of energy used per cucumber is lower (see Section 8).

### 4.4. Crop 8: Specific strategies and production data

The eighth crop of Aviance was planted on 2 March 2006 at a density of three plants per $m^2$. The temperature regimes used to establish and grow the plants were similar to crop 7.

As the light levels increased with extending natural day length, the lights were switched off at 300 W/$m^2$. They were programmed to come back on as light levels dropped in the afternoon unless the total sum of natural light plus supplementary light already exceeded 2000 J/$cm^2$ that day. The aim was to provide enough radiation for optimum crop growth without wasting expensive light from the lamps. The lights were switched off completely from week 24.

The weekly output, measured as marketable cucumbers/$m^2$, is shown in Figure 2. This clearly demonstrates the potential during this cropping period, *i.e.* an average of 9.67 fruits/$m^2$/wk from crop 2, 8.44 fruits/$m^2$/wk from crop 5 and 8.56 fruits/$m^2$/wk from crop 8.

## 4.5. Crop 9: Specific strategies and production data

The final crop of Aviance was planted on 6 July 2006 (week 27) at a density of three plants per $m^2$. The temperature regimes were the same as crop 8.
Following problems encountered with establishment of the previous crop in this period (*i.e.* crop 6 in 2005), the lights were used for two hours prior to sunrise to improve both light levels and plant head temperature. The same temperature effect could have been achieved with a "grow pipe" if one had been available. This approach was successful and there was no repeat of the problems that affected the heads of the plants in crop 6.

From early September, the supplementary lighting strategy returned to that described for the start of crop 8; *i.e.* 17 hours duration with cut off points of 300 $W/m^2$ and 2000 $J/cm^2$.

The weekly output, measured as marketable cucumbers/$m^2$, is shown in Figure 2. Production was poorer than expected, particularly towards the end of the crop, which is clearly illustrated by the reduced gradient of the line in Figure 2 compared to the previous two years. This was an indirect effect of the energy saving regime, which created favourable conditions for infection by *Botrytis* and *Mycosphaerella* (see Section 5). Both pathogens entered the stems at an early stage of the crop and were not controlled by an initial spray of fenhexamid (Teldor). Subsequent applications of iprodione (Rovral) only slowed the plant losses.

The intention was to artificially reduce the plant density of this crop from the initial 3/$m^2$ to 2.5/$m^2$ as natural day length decreased. However, this effect happened naturally due to the disease incidence.

The Qlipr stem clip system continued to be successful and became increasingly popular with crop workers throughout the third production year. However, it proved difficult to make useful labour input comparisons with the standard tomato layering system because the relatively short row length in the experimental glasshouse led to a disproportionate amount of dead time being devoted to moving trollies between rows (see Section 6 and Appendix 1).

## 4.6. Summary of performance in third production year

It is important to gauge the performance of the crops in the third production year relative to best conventional practice so that any seasonal effects can be taken into account. Following a drop in production due to poor light levels in 2004/05 (see Section 3.4), conventional growers' yields in 2005/06 returned to the levels achieved in 2003/04. It is therefore most appropriate to draw comparisons between the first and third years.

Yields for the AYR crops in the third production year were down by 9.1% compared to year one. The performance of the commercial crops shows that this was an actual reduction and did not require a seasonal adjustment. The yield reduction was attributed to the stringent energy saving regime, which successfully reduced the quantity of energy used per cucumber by 9.6% compared to year one (see Section 7.6) but created conditions that were favourable for the establishment of stem diseases. However, Figure 2 clearly illustrates that most of this yield reduction occurred in the third crop (*i.e.* crop 9 compared to crop 3). The energy saving strategy for the first two crops of year 3 should therefore be considered successful, while further modifications are required for the third crop.

With hindsight, there is little doubt that the disease incidence in the final crop could have been reduced by more timely and intensive applications of fungicides prior to the first harvest. However, this would not have been consistent with the CGA's overall policy of reducing pesticide use. It is probable that the situation could have been improved by using more pipe heat in the early stages of the crop although this would have sacrificed a proportion of the energy savings. A similar effect could have been achieved more efficiently with a grow pipe had one been available. These factors should all be taken into account in the future.

**Figure 2. i) Accumulative production expressed as cucumbers per m² over the three years of the project from 2003 to 2006**

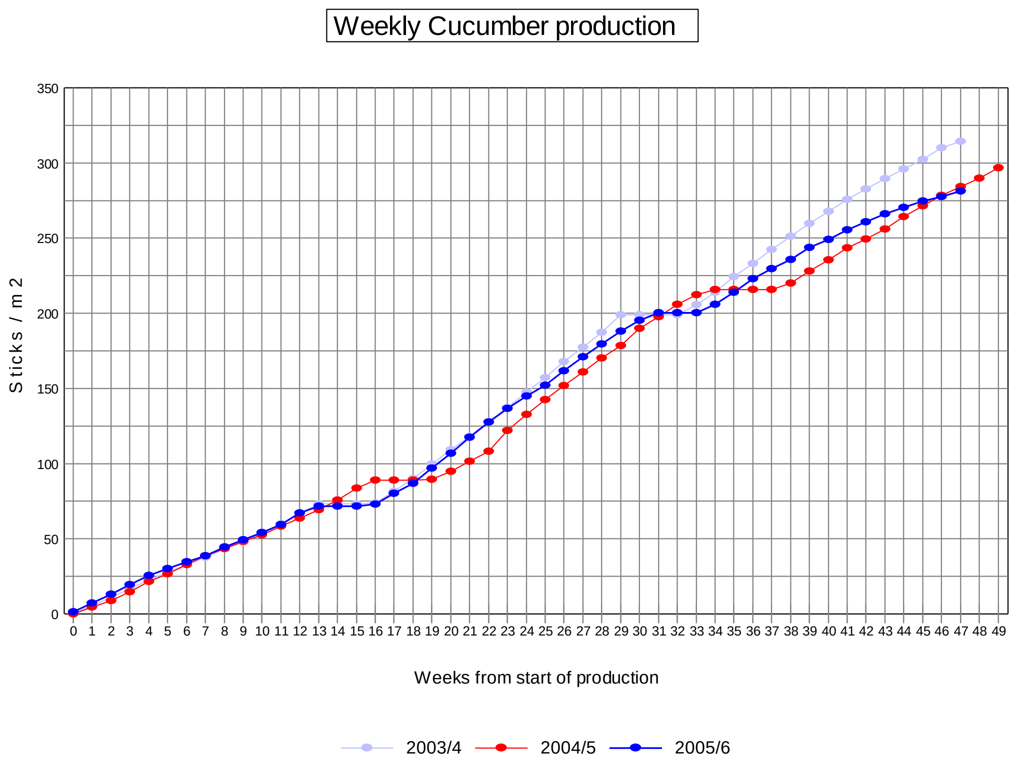



**Figure 2. ii) Summary of cucumber production per crop showing duration and output.**

| | | **Weeks of production** | **Total per crop** | **Total output** |
|---|---|---|---|---|
| **2004** | Crop 1 | 13 | 73.15 /m² | |
| | Crop 2 | 15 | 125.75 /m² | |
| | Crop 3 | 15 | 115.46 /m² | |
| | | | | 314.36 /m² |
| **2005** | Crop 4 | 16 | 89.08 /m² | |
| | Crop 5 | 15 | 126.63 /m² | |
| | Crop 6 | 12 | 80.96 /m² | |
| | | | | 296.67 /m² |
| **2006** | Crop 7 | 13 | 71.67 /m² | |
| | Crop 8 | 15 | 128.54 /m² | |
| | Crop 9 | 15 | 85.60 /m² | |
| | | | | 285.82 /m² |

### 4.7. General observations

Over the three years of the project, there were substantial yield increases (*i.e.* approximately 100%) compared to best conventional practice. With 314.36 cucumbers per $m^2$, the first year showed what was possible with just 10,000 lux of artificial lighting. The energy saving practices that were introduced in the second production year did not have any serious impact on quality or yield. In fact, when a seasonal effect was taken into account, the crop performance actually improved compared to best conventional practice. However, the growing regime was pushed too far in the third crop of the third year and the additional energy saving practices resulted in a marked deterioration in plant health, yield and fruit quality at that time.

It was shown that supplementary light levels of 10,000 lux would allow continuous production of good quality cucumbers through the poor natural light of winter. Production from the second crop was always very good, with above 125 fruits /$m^2$ in each year. The third crop was the most difficult to manage, particularly as the light levels deteriorated through September and October. Our experience suggests that this crop should be planted as early as possible to produce strong plants that are better able to withstand the poor light of Autumn and that plant densities should be reduced before mid September to allow sufficient light to reach lower leaves.

The agronomic data is combined with energy use to provide an economic evaluation of the whole production system in Section 8.

The high wire system (see section 3.3) was originally chosen because the younger and most productive leaves are positioned to maximise light interception. With the cordon system, these leaves are shaded by the older growth around the support wire and it was thought that this would restrict yield. The latter was proven to be correct in two commercial cordon crops which received supplementary illumination during 2003/04 and produced relatively poor output in comparison to the results presented here. The benefits of the high wire system include:

- Improved initial production as plants are not stopped.
- Improved light penetration to the developing fruit giving better fruit colour.
- Developing fruit are able to hang freely and are less likely to produce bents.
- Good air circulation, aiding disease suppression.
- Easier fruit picking because the mature fruit are all in the same position; *i.e.* at the base of the vertical portion of the plant on the otherwise bare stem.
- The growth of the plant and fruit production is clearly sequential, which simplifies evaluation of performance and crop management decisions.
- Frequent leaf removal is believed to contribute to the suppression of establishment of foliar pests and diseases (see section 5).

However, the high wire system requires more labour than conventional cordon crop training systems (Section 6 and Appendix 1). The high wire system will be evaluated without supplementary lighting (HDC Project PC 273) as this could provide considerable benefits to growers without the large investment required for the whole AYR system.

## PART 5: PEST AND DISEASE OBSERVATIONS

### Routine biological control of pests

Routine releases of *Encarsia formosa* (on cards) and *Amblyseius cucumeris* (in sachets) were made from planting against glasshouse whiteflies and onion thrips respectively. Both pests were present in small numbers throughout all three growing seasons. Leaf hoppers were also seen in all crops but the populations remained small and no action was required.

### Specific action against pest and disease

***Crop 1***

- 19 Nov Rubigan – preventative treatment due to mildew elsewhere on site
- 31 Dec Leafhoppers and onion thrips found – kept under observation
- 21 Jan Slight mildew found
- 29 Jan Mildew – curative treatment with Fungaflor
- 29 Jan Mildew – curative treatment with Fungaflor

***Crop 2***

- 26 Feb Filex to block – precautionary treatment to prevent carry over of *Pythium*
- 30 Feb Leafhoppers - kept under observation
- 4 Mar Preventative treatment of Rubigan due to mildew elsewhere on site
- 11 Mar Preventative treatment of Rubigan due to mildew elsewhere on site
- 15 Mar Whitefly found – doubled *Encarsia* input for three weeks
- 31 Mar Onion thrips found - kept under observation
- 30 Apr *Sclerotinia* and *Botrytis* found at base of a few plants, kept under observation.
  Both continued through May and infected plants were removed as necessary.
- 4 May Spider mites found on 3-4 plants were successfully treated with *Phytoseiulus*
- 2 Jun *Mycosphaerella* and *Botrytis* – base of stem sprayed with Amistar / Rovral

***Crop 3***

- 24 Jun Filex to block – precautionary treatment to prevent carry over of *Pythium*
- 2 July Onion thrips found - kept under observation
- 5 July *Botrytis* present on base of some stems – Amistar applied to lower stems
- Through July & August - Leafhoppers and onion thrips present - kept under observation

- 28 July Mycosphaerella found – base of stem sprayed with Amistar / Rovral
- 16 Aug Spider mites in several patches – *Phytoseiulus* applied locally.
- 19 Aug More *Mycosphaerella* found – base of stem sprayed with Rovral / Bravo / Croptex Fungex
- 27 Aug Some *Pythium* seen – Filex applied through irrigation system.
- Early Sept Spider mites increased locally. More *Phytoseiulus* released and one small patch of about 6 plants sprayed with Eradicoat.

***General notes – Year 1***

Leaf hoppers and onion thrips were seen within six weeks of planting the first crop and were found throughout the year. However, the populations remained small and no further action was taken against either species. Whiteflies were found from the start of the second crop and were effectively controlled with routine applications of *Encarsia*. Spider mites were found for the first time in the second crop and localised infestations continued to be found throughout the third crop.

Leaves were removed from the plants within three weeks and this is considered to have suppressed the establishment of all foliar pests and diseases.

There was some powdery mildew in crop 1 but this was effectively controlled with a single spray of Fungaflor. No other diseases were seen in the first crop. There were some difficulties caused by stem diseases in the second crop, which were probably favoured by high stem and leaf densities, and reduced humidity deficit. Although the latter was countered to some extent with the use of ventilation and low level pipe heat, it did not prevent the establishment of *Sclerotinia*, *Mycosphaerella* and *Botrytis*. There were no major plant losses and production was maintained throughout the period. However, when the crop was removed, there was significant *Mycosphaerella* infection present on the old plants. Within a short period of planting the third crop, infections of *Mycosphaerella* were evident at the base of stems and these were followed with infections by *Botrytis*. The control of stem disease in these crops was compromised by the height of the glasshouse, which meant that the lowest leaves and fruit were positioned at the point that the stems became horizontal. This reduced air flow in a critical area and resulted in fruit being in the line of fire of targeted spray applications. In a purpose built glasshouse, the lights would be above the crop and the active part of the stems would be at a slightly higher level; both factors would improve disease management.

***Crop 4***

- 2 Nov Filex to block – precautionary treatment to prevent carry over of *Pythium*
- 18 Nov Rovral/Repulse/Croptex Fungex/Amistar – precautionary treatments to stem bases to reduce risk of carry over of *Mycosphaerella* and *Botrytis*.

- Dec Occasional stems found with beginnings of *Mycosphaerella* – individual stem
  bases painted with chalk
- 4 Jan *Mycosphaerella* – spot sprays to stem bases with Rovral/Repulse/Croptex Fungex/chalk
- 13 Jan Three plants with glasshouse potato aphid - spot treatment of Pirimor to prevent spread
- 7 Feb *Mycosphaerella* – HV spray to stem bases with Rovral/Repulse/Croptex Fungex

***Crop 5***

- 10 Mar Filex to block – precautionary treatment to prevent carry over of *Pythium*
- 25 Mar Amistar – precautionary treatment to stem bases to reduce risk of carry over of
  *Mycosphaerella* and *Botrytis*.
- Apr/May Occasional stems found with beginnings of *Mycosphaerella* – individual stem
  bases painted with Croptex Fungex / chalk
- June *Mycosphaerella* gradually increasing – Croptex Fungex, Repulse/Amistar, and
  Rocket applied to stem bases on 13, 17 and 24 respectively

***Crop 6***

- 20 July Filex to block – precautionary treatment to prevent carry over of *Pythium*
- 21 July Evidence of western flower thrips activity was noted on plants at delivery. Conserve was applied in line with STC's routine plant health policy.
- 29 July Rovral/Repulse/chalk – precautionary treatments to stem bases to reduce risk of
  carry over of *Mycosphaerella* and *Botrytis*.
- 19 Aug Early stages of *Mycosphaerella* infection noted – high volume spray of Rocket
  applied in an attempt to restrict spread
- Aug/Sept Occasional stems found with beginnings of *Mycosphaerella* – individual stem
  bases painted with Croptex Fungex / chalk
- Sept/ Oct *Botrytis* gradually increasing – Rovral, Teldor and Rocket applied to stem bases
  on 3 September, 6 September and 7 October respectively.
- 8 Oct Mildew detected in crop – as plants were soon to be stopped, a high volume

spray of Rocket was applied to prevent establishment during the final 3 weeks.

***General notes – Year 2***

Traces of thrips, whiteflies and leafhoppers were present throughout this period but the populations remained small. Spider mites were not seen despite being present in the previous crops. A small patch of glasshouse potato aphid was found in January. This is an unusual pest on cucumber and the population appeared to be developing quickly on the growing points and young fruit causing severe distortion. A spot spray of an IPM compatible aphicide (Pirimor) was applied to prevent further spread. This was completely successful and the pest was not seen in the crops again.

Compared to conventionally grown commercial crops, there was very little powdery mildew on these plants. This was no doubt due to a combination of using the mildew tolerant cultivar, Aviance, and frequent leaf removal. Only one foliar spray was applied and this was done as a precaution after the growing points had been removed towards the end of the autumn crop.

Stem diseases were present to variable degrees in these crops. In previous crops, the latter had been countered by the use of ventilation and low level pipe heat. However, the main objective this year was to be more energy efficient and ventilation was restricted to reduce energy losses from the glasshouse and to retain the released carbon dioxide.

The presence of *Mycosphaerella* was first recorded in December 2004. The disease was managed with spot treatments to the base of individual infected stems until early February when a more general treatment was applied throughout the crop. There was minimal impact on the yield of crop 4. This disease was more prevalent in crop 5 and three high volume sprays were applied during June. However, with hindsight, it was felt that *Mycosphaerella* could have been better managed by improved control of irrigation timing to keep the lower stems drier in the early part of the illuminated day. A different strategy was therefore adopted for crop 6, with irrigation only being applied during a restricted period during the day.  Watering began four hours after the lights came on with only small amounts (200-250 ml/$m^2$) every 2 hours until 2 hours after sunrise. A more normal regime was then used aiming for 300 ml/$m^2$ for every 100 J/$cm^2$ of radiation until 2 hours before sunset. No water was applied from 2 hours before sunset until 4 hours after the lights were switched on.  The incidence of *Mycosphaerella* was much reduced in crop 6 with only occasional stems being found with early stages of the disease. This strategy was further evaluated in the third year of production.

*Botrytis* was the most common disease in crop 6 and by late October approximately 8% of plants had been killed despite three applications of fungicides through September and October. As a consequence of this “natural” thinning, the planned reduction in plant density from 3 to 2.5 plants per $m^2$ was not necessary as the crop entered

Autumn. The incidence of this disease was probably exacerbated by very vigorous plant growth during the first few weeks (ie thick stems and large leaves), which is known to make plants more susceptible to *Botrytis*. With hindsight, the combined effects of a delay in the application of the first fungicidal treatment, followed by the choice of Teldor for the second application, allowed the disease to gain an unacceptable foothold. Earlier use of a protective chemical may therefore be needed in the future. However, we believe that this disease would be better managed by improved control of the environment and the use of a grow pipe at the height of the stem bundles. Although this option is not available in this experimental glasshouse, we would recommend it in a commercial crop.

***Crop 7***

- 9 Nov Filex to block – precautionary treatment to prevent carry over of *Pythium*
- 21 Nov Rovral/Repulse/chalk – precautionary treatments to stem bases to reduce risk of carry over of *Mycosphaerella* and *Botrytis*.
- 26 Jan Early stages of mildew detected - Agrikarb/Potassium bicarbonate applied
- 2 Feb Further spray of Agrikarb/Potassium bicarbonate against mildew
- 9 Feb Continuation of Agrikarb/Potassium bicarbonate spray programme
- 16 Feb Continuation of spray programme against mildew with Agrikarb/Potassium bicarbonate/Eradicote
- 24 Feb Continuation of spray programme against mildew with Agrikarb/Potassium bicarbonate/Eradicote

***Crop 8***

- 2 Mar Filex to block – precautionary treatment to prevent carry over of *Pythium*
- 8 Mar Protective treatment against mildew – Rubigan
- 21 Mar Protective treatment against mildew – Rubigan
- 5 May Protective spray to bare stems against *Mycosphaerella* - Repulse

***Crop 9***

- 7 July Filex to block – precautionary treatment to prevent carry over of *Pythium*
- 4 Aug Additional root drench with Filex against *Pythium*
- 10 Aug Protective spray to bare stems against *Mycosphaerella* with Repulse
- 25 Aug Protective spray to bare stems against *Botrytis* with Teldor
- 1 Sept Rovral applied to stems to control *Botrytis*
- 20 Sept Rovral applied to stems to control *Botrytis*

***General notes – Year 3***

Leaf hoppers and onion thrips were found throughout the year but the populations remained small and no further action was taken against either species. Small numbers of whiteflies were found soon after crop 8 was planted and were controlled with routine applications of *Encarsia*. Localised infestations of spider mites were found occasionally during the summer / early Autumn but were effectively controlled by a combination of leaf removal and release of predatory mites.

Powdery mildew was present throughout the last month of crop 7 but its development was slow on the mildew tolerant cultivar, Aviance, and was further restricted by the frequent leaf removal. Following the recent loss of Fungaflor, there was no longer an effective fungicide for remedial use after picking had begun. A precautionary spray programme based on Agrikarb, potassium bicarbonate and Eradicote T was therefore implemented to help suppress the establishment of the pathogen. As a further precaution, two protective sprays of Rubigan were applied before the first harvest of crop 8. No further treatments were required against this disease in crops 8 or 9.

Stem diseases were virtually absent from crop 7 and while *Mycosphaerella* was seen in crop 8 it didn't cause any significant damage. However, *Mycosphaerella* and *Botrytis* rapidly established on the lower stems of crop 9 and both pathogens thrived under the conditions created in the glasshouse by the energy saving environmental management regime. Early sprays of Teldor and Repulse failed to give adequate control and the use of Rovral during September / October only slowed the spread of the pathogens. Approximately 30% of the plants were killed by stem diseases between September and November. As in 2005, this "natural" thinning obviated the need for the planned reduction in plant density as the crop entered Autumn. The overall effects of the disease were not therefore as devastating as it may at first seem.

# PART 6: LABOUR REQUIREMENTS

Labour use in commercial cucumber crops varies considerably from nursery to nursery and is dependant on the following factors:

- Yield
- Block size and row length
- Growing system
- Crop support systems
- Harvesting system
- Skill levels of labour force

The main labour consideration in this project was to compare the requirement of high wire and conventional cordon-trained crops. The tasks and labour input are similar until the plants reach the support wire but thereafter become very different. In a cordon crop, most of the labour is then devoted to finding and picking fruit that are in random positions within the proliferation of foliage. By contrast, in the high wire system, only a small proportion of time is devoted to picking because the location of the fruit is predictable and they are easily accessible. Instead, the majority of the labour is required to remove side shoots and unwanted fruit, twist new growth into the support strings, remove old leaves and layer the plants. It was known from best commercial practice that cordon crops required about two crop workers per 5000m$^2$. However, it proved difficult to determine such a figure in the experimental high wire system because the relatively short row length led to a disproportionate amount of dead time (*i.e* moving trollies between rows etc). It was also difficult to look at crop training and harvesting in isolation because they were influenced by many other factors.

As the experimental high wire facility gave an unrealistic impression of labour use, it was decided to undertake a separate desk study to analyse labour input in different types of commercial production units in the UK and Netherlands. This study was completed by Derek Hargreaves and is presented as a "stand-alone" report in Appendix 1.

# PART 7: THE CROPPING ENVIRONMENT AND ENERGY INPUTS

## 7.1. Introduction

The following section gives a summary of the key findings related to energy use and glasshouse environmental control over the three production years of the project thus allowing comparisons to be made between the strategies used in each year.

## 7.2. Heat energy use

Figure 3 shows the total amount of heat used in $kWh/m^2$ in the preceding 52 weeks and Table 1 summarises the total heat use in the 52 weeks up to Week 44 in each year of the project. The latter has been converted into an equivalent amount of gas assuming a boiler efficiency of 85%.

**Figure 3 – Heat used in preceding 52 weeks**

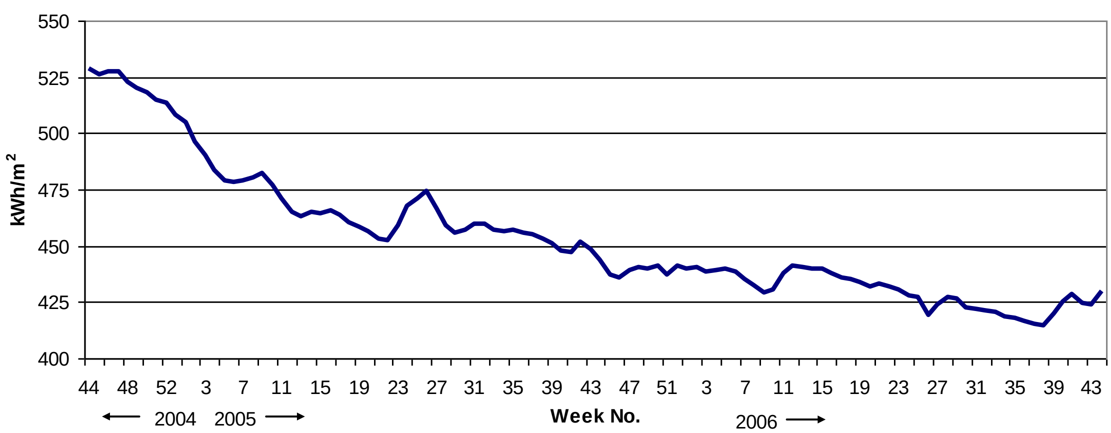



**Table 1 – Annual heat use to week 44 of each production year**

| Year | Heat use ($kWh/m^2$) | Gas use ($kWh/m^2$) | Saving (gas) compared to 2003/04 |
|---|---|---|---|
| 2004 | 529 | 622 | |
| 2005 | 444 | 522 | $100kWh/m^2$ (16%) |
| 2006 | 430 | 506 | $116kWh/m^2$ (19%) |

The savings in heat use were achieved against a backdrop of reduced use of the supplementary lighting installation. In isolation this would have caused an increase in heat use. Therefore, the overall saving of 19% does not fully reflect the progress made in reducing heat use through the duration of the trial.

The additional energy savings achieved in 2006 compared to 2005 were delivered by a continued focus on humidity control. The over-riding 'rule' in 2006 was that humidity influences were only allowed to increase the minimum pipe temperature to a maximum of 50°C. This was regardless of the time of day or humidity deficit measured in the greenhouse. This was not possible without the continued focus on crop management decisions in relation to disease control.

### 7.3. Electricity use

Figure 4 shows the total amount of electricity used in kWh/m² in the preceding 52 weeks and Table 2 summarises the total electricity use in the 52 weeks up to Week 44 in each year of the project. A steady reduction in electricity use continued through 2006. This was due principally to reduced lighting hours driven by the needs of the crop rather than by improved control set points.

**Figure 4. Electricity use in preceding 52 weeks**

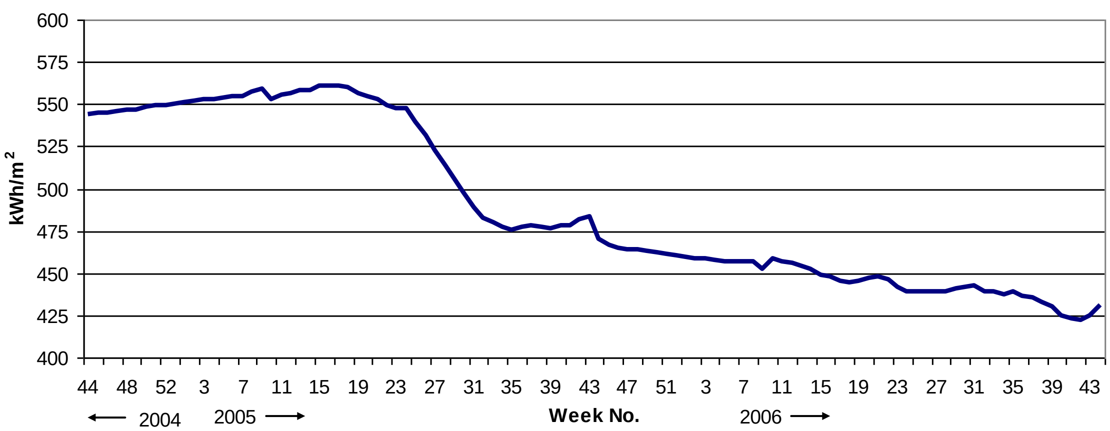



**Table 2. Annual electricity use to week 44 of each production year**

| Year | Electricity use – kWh/m² | Saving compared to 2003/04 |
|---|---|---|
| 2004 | 544 | |
| 2005 | 470 | 74kWh/m² (14%) |
| 2006 | 431 | 113kWh/m² (21%) |

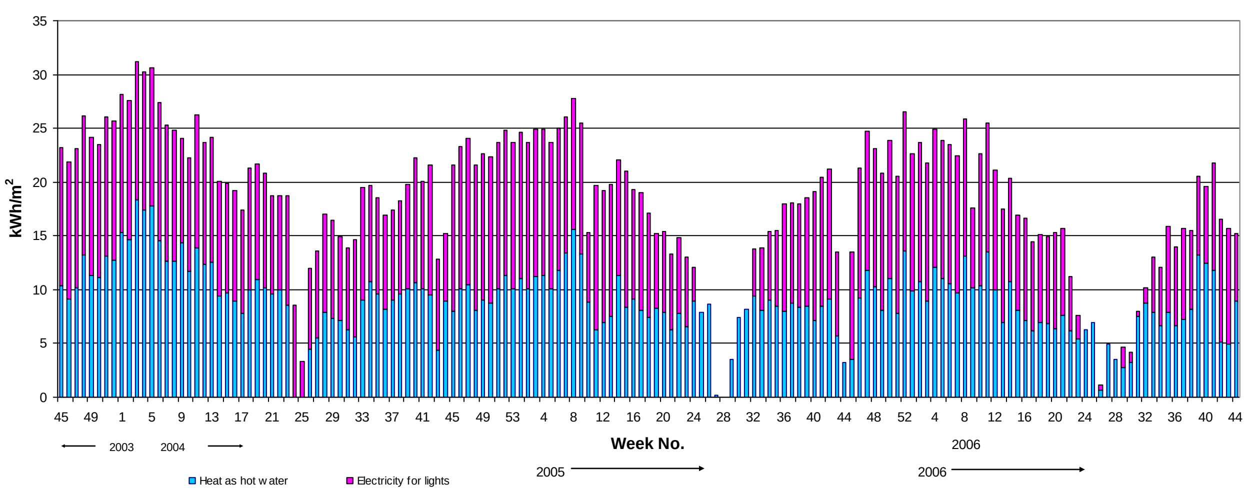
### 7.4. Summary of energy use per crop

Table 3 summaries the total energy used per crop and Figure 5 shows the profile of energy per week throughout the whole trial.

**Table 3. Energy consumption per crop**

| | Date in | Date out | Heat energy used kWh/m² | Lights - total operating hours | Electricity kWh/m² |
|---|---|---|---|---|---|
| Crop 1 | 6-Nov-03 | 24-Feb-04 | 214 | 1,977 | 202 |
| Crop 2 | 26-Feb-04 | 16-Jun-04 | 154 | 1,602 | 163 |
| Crop 3 | 22-Jun-04 | 19-Oct-04 | 143 | 1,554 | 159 |
| Crop 4 | 29-Oct-04 | 7-Mar-05 | 198 | 2,413 | 246 |
| Crop 5 | 10-Mar-05 | 13-Jul-05 | 135 | 1,324 | 135 |
| Crop 6 | 19-Jul-05 | 28-Oct-05 | 118 | 1,041 | 106 |
| Crop 7 | 8-Nov-05 | 27-Feb-06 | 161 | 1,989 | 203 |
| Crop 8 | 2-Mar-06 | 3-Jul-06 | 133 | 1,264 | 129 |
| Crop 9 | 6-Jul-06 | 3-Nov-06 | 129 | 960 | 98 |
| Total for 03/04 season (Crops 1-3) | | | 511 | 5,133 | 524 |
| Total for 04/05 season (Crops 4-6) | | | 451 | 4,778 | 487 |
| Total for 05/06 season (Crops 7-9) | | | 423 | 4,213 | 430 |
| | | | | | |
| **Total** | | | **1,385** | **14,124** | **1.441** |

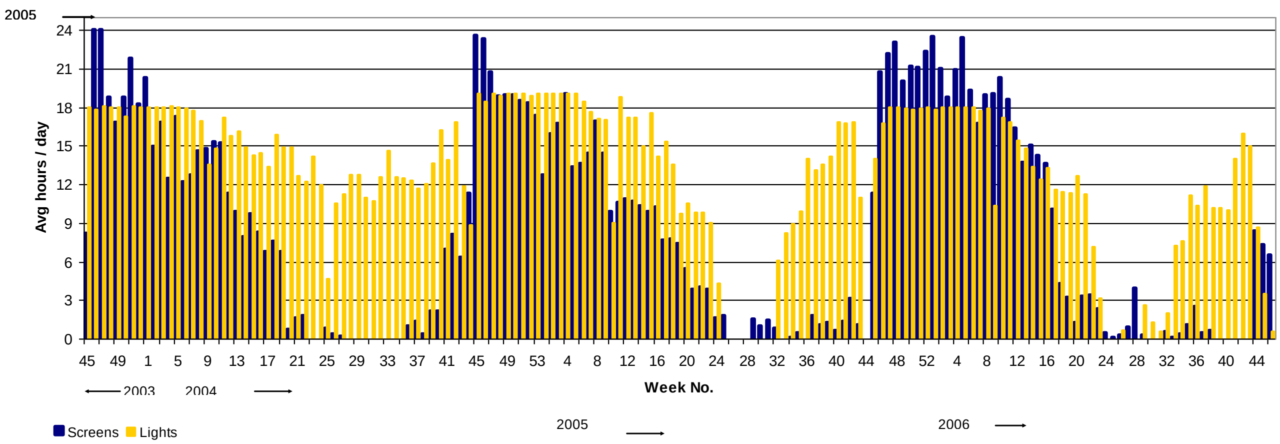
**Figure 5. Profile of energy use by the facility per week**



## 7.5. Thermal screen & lights operating hours

The average operating hours per day for both the screen and lights are shown in Figure 6.

**Figure 6. Screen & lighting hours expressed as average hours closed per day**




## 7.6 Summary of energy inputs

A direct comparison of the total amount of energy used in each cropping year can be misleading due to slight variations in the length of the year. From an energy use perspective, the specific energy consumption (SEC) per cucumber produced is a more useful figure. For greatest commercial relevance it is necessary to use the entire area of the glasshouse (*i.e.* including the concrete roadway and other non-cropped areas) rather than just the cropped area. Therefore the 'headline' yield quoted elsewhere in this report has been reduced to account for a greenhouse where only 95% of the total area is cropped (Table 4). The yield of the conventional crop in each year was determined from data collected from commercial growers. In addition, from a climate change levy (CCL) perspective it is the gross amount of fossil fuel energy used that is important. This depends on how the heat and electricity is generated.

**Table 4. Yields adjusted to allow for uncropped areas in glasshouses**

| Production year | AYR crop | | Conventional crop |
|---|---|---|---|
| | Yield (cucumbers/m²) from production area | Yield (cucumbers/m²) to whole area | cucumbers/m² |
| 2003/04 | 314 | 300 | 136 |
| 2004/05 | 297 | 282 | 123 |

| | | | |
|---|---|---|---|
| 2005/06 | 286 | 272 | 138 |

The results in terms of SEC per cucumber are expressed in Table 5 and show three scenarios:

*Scenario 1* – Conventional production with no supplementary lighting.
*Scenario 2* – Heat from a gas fired boiler & electricity from the mains network. This assumes an average boiler efficiency of 85% and standard CCL conversion factors for mains electricity.
*Scenario 3* – Heat & electricity from a combined heat and power unit

**Table 5: Specific energy consumption per cucumber (SEC) under three production systems during 2003/04 and 2004/05**

| Production System | SEC (kWh/cucumber) | | | Change compared to 03/04 - % |
|---|---|---|---|---|
| | 2003/04 | 2004/05 | 2005/06 | |
| 1. Conventional | 4.23 | 4.79 | 4.02 | -5.0% |
| 2. Lit – Mains Electricity | 6.55 | 6.37 | 5.80 | -11.5% |
| 3. Lit - CHP | 4.16 | 4.11 | 3.76 | -9.6% |

This shows a sustained reduction in the SEC of the lit crop as the project progressed. The significant reduction in the conventional crop SEC in 05/06 compared to 04/05 is the result of both an increase in yield and a reduction in energy use. However, it is interesting to note that the lit crop (CHP) used 2%, 14% and 7% less energy per cucumber than the conventional crop in 2003/04, 2004/05 and 2005/06 respectively.

# PART 8: AN ECONOMIC EVALUATION OF AYR PRODUCTION

Table 6 summarises the estimated financial returns during each year of the project for 4000m2 (approx one acre) of conventional production compared to AYR production using i) gas fired boiler and mains electricity, and ii) combined heat and power. The figures were calculated using the spreadsheet shown in the first annual report (Jacobson, Hargreaves, Plackett & Pratt, 2005) although some figures have been slightly adjusted to take into account new information.

The yield figures entered for conventional production in 2003/04 and 2005/06 were 136 and 138 cucumbers per m2 respectively, which were higher than the national average but should have been achievable for most growers with modern glasshouse facilities. The figure for the intermediate year (2004/05) was reduced by 12% to reflect the drop in production experienced by the best practice commercial grower partners. The yield figures entered for AYR production are based on the actual yields achieved each year in the experimental facility corrected to allow for the uncropped areas of the glasshouse.

Figures for energy use for conventional crops are based on data from the best practice growers, while those for AYR production are extrapolated from the actual energy use in the experimental glasshouse (see Section 7). Gas and electricity prices were taken as 1.3 and 3.8 p/kWh respectively for 2003/04, 1.5 and 4.5 p/kWh respectively for 2004/05, and 2.3 and 6.0 p/kWh respectively for 2005/06. The value of produce is based on the prices paid by marketing organisations in each year.

The figures for 2004/05 and 2005/06 have been presented in two forms. The first form shows actual energy use for those years but uses energy prices from 2003/04, so that it is possible to make a direct comparison and see the benefit of the energy reductions over the course of the project. The second form uses actual energy use and actual energy prices, so that it is possible to see the impact of the increasing energy prices.

In 2003/04, the financial surplus for AYR crops grown with boiler / mains electricity and for AYR crops grown with CHP would have been £26.9k and £39.9k greater per acre (£66.4k and £98.5k greater per hectare) respectively than conventional production.

Using the same energy prices, in 2004/05 the surplus for AYR crops with boiler / mains electricity and for AYR crops with CHP would have been £32.5k and £43.9k greater per acre (£80.3k and £108.4k greater per hectare) respectively than conventional production. This clearly demonstrates that the measures taken to reduce energy were successful.

However, energy prices rose considerably during that time and when this is taken into account the financial benefits are quite different. At the higher energy prices, the surplus for AYR crops with boiler / mains electricity and for AYR crops with CHP would have been £18.4 and £32.1k greater per acre (£45.4k and £79.3k greater per hectare) respectively than conventional production. This would still have been economically viable for growers who had the necessary equipment in place but it was clearly becoming a less attractive option for those who were considering making an investment in a new AYR facility.

Energy prices continued to rapidly rise during 2005/06 and were extremely variable. In an attempt to reduce their expenditure, many conventional growers invested in climate control screens and other methods of saving energy. These practices resulted in an estimated 5% reduction in the quantity of energy consumed per cucumber between 2003/04 and 2005/06 (see Section 7.6). The instability of the energy market caused more complications for CHP operators whose prices for selling and buying electricity have varied greatly. In fact, the variations in energy usage, energy prices, repayment of capital investments, other production costs and value of produce have made it increasingly difficult to prepare representative figures for financial returns for both conventional and AYR production. The figures shown in Table 6 for the 2005/06 season should therefore be treated with caution, but they do provide a useful guide to recent trends. In the longer term, it will clearly be necessary to calculate financial returns independently for each grower / scenario.

Using energy prices from 2003/04, the surplus in 2005/06 for AYR crops with boiler / mains electricity and for AYR crops with CHP would have been £14.6 and £25.4k greater per acre (£36.1k and £62.7k greater per hectare) respectively than conventional production. Comparison with the surplus in 2003/04 indicates that the reduction in yield in 2005/06 was not offset by the savings in energy. However, we know that there is scope to improve yields from the Autumn crop (see Section 4.6) which would close the gap between the two years.

When calculations are based on the high energy prices of 2005/06, the surplus for AYR crops with boiler / mains electricity and for AYR crops with CHP would have been £2.1 and £20.1k per acre (£5.2k and £49.6k per hectare). At these prices, AYR production based on CHP would still be financially viable for growers who had the necessary equipment in place. However, the initial investment could no longer be justified because the financial returns from AYR production with CHP were now similar to conventional production.

It should be noted that this scenario has once again changed because at the time of completing this report (March 2007) energy prices had fallen significantly.

In the future, it may be appropriate to consider other variations on AYR production. For example, yields are relatively low in early winter even with supplementary lights and the price of produce is kept low by imports from Spain, so it may prove sensible to delay planting until December and then use the lights to boost early season production. However, in practice, the final decision on whether to adopt AYR production technology will probably be driven by the demands of the retail customer.

As stated above, a single set of calculations will never be applicable to all growers due to the variations in facilities and output. However, a spreadsheet has been produced that will take many of these variables into account and this could be used to produce personal predictions for individual growers. The spreadsheet will be made available to HDC levy payers later in 2007 as part of a Factsheet that will summarise the key findings of this project.

**Table 6. Estimated financial returns for one acre of conventional production compared to one acre of AYR production using i) gas fired boiler and mains electricity and ii) combined heat and power.**

| | Financial surplus after subtracting those variable costs specific to the project (labour, energy, plants and depreciation on the lighting equipment) from the income for sale of produce | | | | |
|---|---|---|---|---|---|
| | 2003/04 | 2004/05 | | 2005/06 | |
| | | calculated with 03/04 energy prices | calculated with 04/05 energy prices | calculated with 03/04 energy prices | calculated with 05/06 energy prices |
| Conventional | £43,740 | £29,352 | £25,194 | £44,538 | £19,538 |
| AYR with boiler/mains electric | £70,681 | £61,820 | £43,635 | £59,110 | £2,110 |
| AYR with CHP | £83,691 | £73,308 | £57,248 | £69,999 | £20,110 |

## PART 9: DISSEMINATION OF INFORMATION

The project operated on the basis of continuous transfer of knowledge and technology. CGA members were regularly updated on progress via the Annual Conference, CGA Newsletters and Committee meetings. In addition, results were displayed on the CGA web site.

Progress with the project has been reported to HDC members via HDC News on several occasions, most recently in the January 2006 issue.

The facility has been visited by many individuals and groups of cucumber growers, tomato growers, suppliers to the horticultural industry, retailers, politicians and overseas visitors. A final Open Day for CGA and HDC Members was held on the 29 September 2006.

The project has also received much general publicity via horticultural and farming journals, local and national press, local and national radio, and BBC television. The most recent feature being in the Grower in October 2006.

## ACKNOWLEDGEMENTS

The Project Management team would like to thank the following companies and organisations who have all made important contributions to the facility, crop production, marketing and sale of produce:

BCP Ltd, Cavegates Nursery, CGA Technical Committee, CMW, Ecotech, EVS, Green Meteor, Glen Avon Growers, Grodan UK, Hedon Salads, HDC, Hortilux Schreder, Priva, Leen Huisman, Ludvig Svensson, Marks and Spencer, Melrow Salads, Rijk Zwaan, Plant Raisers Ltd, Syngenta Bioline.

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# <u>Appendix 1.</u>

## A desk study of labour use in cucumber production

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# CONTENTS



 

## Executive summary

### Reasons for the study

- The use of high wire crop training for AYR cucumber production in HDC project PC 201 (Cucumber: A technical and economic evaluation of AYR production) identified the importance of labour input to the success of this production system.
- Anecdotal evidence suggested that Dutch nurseries were more efficient in labour use than those in the UK.
- Alternative layering systems had been introduced into high wire systems in Holland that had the potential to reduce the amount of labour required.

### The Approach

- The study involved analysing labour use data from nurseries in the UK and Holland.
- The report describes the range of production, harvesting and pack house work practices.
- The more efficient and inefficient work practices were identified.

### Findings

- Recording labour use in detail was universal in Holland but rare in the UK.
- There was considerable variation in labour use from grower to grower.
- This variation was seen within the UK as well as between the UK and Holland.
- The total labour used for conventional production of long season cucumbers in the UK ranged from 750 to over 1,150 hours per 0.1ha.
- The main reason for the variation was the range of cropping systems used - the number of crops per season and the length of the crop rows had the greatest impact. However, some of the variation was simply caused by differences in the skill of workers and / or the managers / supervisors directing the work.
- The labour used for all production tasks in Holland ranged from 600 to 900 hrs per 0.1ha for conventional production systems, and from 900 to over 1,400 hrs per 0.1ha for high wire crop training systems.
- The greater labour involved with the increasing numbers of crops and / or the high wire production system was offset by improved yield and quality of produce.
- The popularity of high wire crops had fluctuated in Holland mainly due to the greater labour costs that were initially involved. However, this is now being reduced with increasing experience and with the adoption of "clipper" systems.
- Further breakdown of the labour used on different tasks was very difficult due to the lack of reliable data.

### Conclusions

- Labour costs are the second largest item in the production of long season cucumbers and must be better understood.
- UK cucumber growers should adopt a form of labour recording that details the various tasks involved in production so that useful comparisons can be made and

efficiency improved.

## Introduction

The most important comment to make about labour comparisons in UK cucumber production is that many growers have little information about how their workers spend their time. Very few keep accurate records of individual tasks but just record the total time spent "working". It is possible that a nursery could have a superbly efficient harvesting system but a totally inefficient crop trimming system - or vice versa - but this wouldn't be quantified unless they had separate records of each activity. In fact, the most important activity in labour use should be recording that use in detail so that comparisons can be made between workers and between nurseries. This has been practiced for many years in the Netherlands; eg Bedrijfsregistratie, which was introduced in the 1980's, recorded all aspects of the business including labour use. UK growers should carry out a similar exercise. The most useful end product from this exercise would be a move by the industry to record and compare that data.

Direct comparisons between nurseries are virtually impossible due to the differences in size and system of production. However, overall labour use comparisons can be used to judge the efficiency from one site to another.

There is a problem making comparisons between different sites that grow cucumbers because there is not a single system to compare.  Planting dates vary and the number of crops grown per season also varies.

The earliest planting's are early December. However, due to the rapid increase in energy costs there has been a move to planting in early January. This trend been more noticeable in the UK because energy prices are higher than in Holland.

Labour use per unit area varies considerably from grower to grower and is dependant on a number of factors:

- Yield
- Glasshouse block size
- Row length
- Growing system
- Crop support systems
- Harvesting system
- Skill levels of labour used

As the yield increases so does the labour needed to produce that yield.  It is a simple matter of logistics to know that if you increase the number of fruits produced, then you will have to increase the amount of time taken to pick those fruits. However, that extra time depends on the work systems being used.

There are effectively two approaches to annual production; *i.e.* based on two or three crops per season. These crops may take up the same period - planting the first in

January and ending the season in late October / early November. The amount of labour required in each method will vary because the three crop system will need more labour for planting / re-planting and working the crop up the string to the wire. On the other hand, the two crop method will need more labour for leaf removal and crop trimming to maintain good crop growth and good quality of fruit. Shorter crops are grown in the same way.

Block size and row length have a significant effect on the time taken to carry out the various tasks needed to produce and harvest cucumbers. The longer the rows the better the rhythm of the workforce and the more efficiently the tasks are carried out - to an upper limit that seems to be around 110m in Holland. Smaller blocks obviously have shorter rows and the amount of labour hours per square metre climbs as the block area reduces because more time is spent on "end of row tasks".

## Systems of production

There are effectively four growing systems:

- the original "A" frame, which is still used by a few growers in the Lea Valley area
- 3.2 m bays
- 1.6m track (or pipe rail) systems
- high wire systems - usually on 1.6m track systems.

Comparison of the systems is complex because the high wire system has an increased production but can have a greatly increased labour input. High wire systems are also sub-divided into tomato bobbin systems, clipping systems (now Pelikaan or "Qlipr" clips) and the moving wire systems (eg the new "Metazet" system).

On top of this, harvesting is also sub-divided into various systems involving different methods of handling produce in both the glasshouse and packhouse. The crop is usually cut into plastic trays that are man-handled from cutting trolleys or monorail systems onto pallets or transport trolleys for transfer to the pack house. There are many examples of manual, semi-automatic and automatic box handling systems in the pack house. Other growers use minimal handling systems or purpose built self emptying bins that reduce harvesting and grading labour but involve considerable investment.

One of the greatest factors is the skill level of those involved, which can be placed in four categories:

- Skilled full time workers
- "Students" - usually from Eastern Europe - whose skill level is often similar to full time workers and whose speed and dexterity is often superior
- Agency workers - very variable but usually poor skill levels
- School children - not so evident in the UK but still quite common in Holland.

So, on the face of it a simple comparison becomes extremely complex because of the variety of different methods used in producing the humble cucumber. Before looking at labour in detail, it is therefore worthwhile giving a brief outline of the various systems in use.

**The “A” Frame System**

The “A” frame is all but discontinued now with only a very small area left in the Lea Valley (Figure 1.1).

**Figure 1.1: The “A” frame system (showing half the house)**

**The Cordon System**

The majority of production is on the cordon system where the crop is grown to a wire fixed at <2.2 m above the ground. The head of the plant is removed when it reaches the wire and (usually) two laterals are then taken - these are then stopped a certain distance below the wire and sub-laterals are taken and so on until the crop is removed. This system also requires some element of leaf removal and trimming to maintain good production and to aid harvesting.

The original system used a standard Venlo bay width of 3.2 m with plants at each side of the bay (Figure 1.2) but most growers have now moved to the “pipe rail” system which has plants grown at 1.6 m centres (Figure 1.2). The pipe rail system increases harvesting speed because less time is spent “hunting” for fruit to harvest - even though the workers have twice as far to travel to carry out the harvesting operation. There can be problems with fruit marking due to the close proximity of harvesting trolleys to the fruit.

**Figure 1.2: Cordon system based on 3.2m (left) and 1.6centres (right)**

**The High Wire System**

This is a direct copy of the layering system used by tomato growers; *i.e.* using layering hooks to lower the crop as the stem extends thereby keeping the plant head close to the crop wire and in the best light (Figure 1.3). This is the system to use with supplementary lighting for improved growth (Figure 1.4). Essentially, it is the pipe rail system, with a wire height between 3.5m and 4 m, allowing only stem fruit to be produced. This makes harvesting much easier as the stem fruit are always presented in the same place and removal of side shoots / leaves means that they are not hidden by excess foliage. However, it does take more labour to maintain the crop - removing leaves and layering etc.

**Figure 1.3: High wire system (about to be de-leafed)**

**Figure1.4: High wire under lights (showing layering system)**

 

Early attempts at using this system aimed at having one crop for the whole season - but the vigour of each plant could not be maintained and re-planting was used to maintain the vigour.

There have been various attempts to reduce the labour requirement in the high wire system. Initially, leaves were left on the plants but this resulted in many problems because the fruit could not be found easily and disease build up was rapid. Clipping systems have since been introduced but most have not been very popular. The best to date is probably the system developed by Cor Pelikaan in Holland and marketed as Qlipr. This uses a foam padded stainless steel clip that grips the stem and holds it from a rod suspended from the crop wire (Figure 1.5).

**Figure1.5: Qlipr system of stem support**

Systems with moving wires, designed to improve work rates for crop maintenance and harvesting, have been introduced but no data is available to evaluate them against "standard" systems. The latest technique to be introduced in Holland is a moving wire system developed by **Metazet** (Figures 1.6). This uses a crop support wire that is lowered to facilitate picking. Using this system, the crop is grown similar to a high wire crop but is stopped after a few weeks of growth. The wire is lowered every few days to allow picking to take place at a convenient height. The claimed advantages are i) more straight cucumbers (but that is a feature of all high wire crops) and ii) no leaf removal (thus reducing the labour requirement). Inter-planting is used to maintain output. This system is interesting but needs further evaluation.

**Figure 1.6: Metazet moving wire system with Crop worker (right)**

 

## Harvesting fruit

A further layer of complication is added by harvesting systems. There are a number of basic systems:

### Mono-rail systems

Mono-rail systems are used where the row spacing is 3.2 m and where a mono-rail cart is carried from a pipe suspended above the crop (Figure 1.7). This system was widely used but has now been superseded by other systems using pipe-rail carts. However it is still used on some nurseries and provides a reasonable solution where soil levels are uneven and no pipe rail system is installed. The drawback with the system is that all filled boxes have to be double handled from the mono-rail cart to another system for removal from the glasshouse (usually a pallet for handling with a hand pallet truck or similar).

**Figure 1.7: Mono-rail cart (left) and palletised boxes**

### Pipe-rail systems

The pipe-rail system is used at 3.2 m and 1.6 m centres. The harvesting cart uses the heating pipe for guidance. There are three basic types of carts in use:

1. Where boxes are stacked on the cart then removed at the end of the row for transfer to another system for removal from the glasshouse - thus double handling the boxes. The filled boxes are moved to pallets before removal by hand pallet or

fork lift equipment. (Figures 1.8 to 1.10).

**Figure 1.8: Pipe-rail cart ready for use (left) and in use**

**Figure 1.9: Filled boxes transferred to pallet (left) and awaiting collection**

**Figure 1.10: Empty boxes returned and ready for refilling**

2. Where boxes are stacked on the cart but then full carts are made into ‘trains’ to be removed to the packhouse - thus removing much of the double handling of the first system. There is some moving of boxes to make up full carts before transferring to the pack house but less than in the previous system. (Figure 1.11)

**Figure 1.11: Boxes are filled as in the first system (left) but then made in trains (right)**

3. Specially constructed bulk bins are used instead of boxes. When filled, they are made into ‘trains’ to be moved to the pack house. With this system the cucumbers are only handled once in the growing house. (Figure 1.12)

**Figure 1.12: Bulk bins in use during harvest (left) and made into trains for transport to packhouse**

 

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## Work in the pack house

Each of the systems described for harvesting requires a different handling system in the pack house. Pallets of boxes can simply be man handled onto the grading area and emptied for grading - this requires most labour and has the potential to result in repetitive strain injury unless jobs are rotated regularly. There are various systems for tray handing to de-stack and de-pallet for grading:

**Figure 1.13: Palletised boxes with automatic de-stacking and tipping**

**Figure 1.14: Picking cart transport with automatic de-stacking and tipping**

**Figure 1.15: Bulk bin system with automatic tipping**


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## Summary of findings

The number of hours worked reflect the organisation of the nursery; generally speaking, the longer the paths (up to an optimum of about 100m) the more efficient the work. One factor that became clear during this exercise was that many growers did not keep labour records that distinguished between the various processes of crop production. If no breakdown is available, it is not possible to tell whether one action is being carried out more efficiently than another. Labour recording systems such as those provided by Hoogendorn and Priva supply useful information on the time taken to carry out recorded tasks.

An example of labour breakdown for a production system in Holland is shown in Table 1.1. This was a three crop sequence planted in late December that yielded 170 cues / $m^2$. The clarity of the information illustrates the level of detail that can be made available. However, it was not all good news because almost 25% of the labour use in this example was not allocated to specific tasks.

**Table 1.1. Example of labour use in a three crop sequence planted in late December and yielding 170 cues / $m^2$ (all figures quoted are per 1,000 $m^2$)**

| | | |
|---|---|---|
| **Harvest:** | 257 | |
| **Grading:** | 137.5 | |
| **Putting plants on slab:(3x)** | 10.4 | |
| **Twisting:** | 56.3 | |
| **Stopping :** | 10.53 | |
| **Put laterals over wire:** | 41.44 | |
| **Tying strings to wire:** | 8.7 | |
| **Leaf Trimming:** | 4.7 | |
| **Fruit thinning:** | 85.5 | |
| **Tying plants to sting:** | 17.11 | |
| **Biological treatment:** | 6.2 | |
| **Chemical treatment:** | 5.7 | (Mainly LVM & some spraying) Note: Low pressure of Mildew that year. |
| **Removing old crop (3x):** | 15.6 | |
| **Removing rockwool cubes:** | 2.9 | |

| | |
|---|---|
| **Install plastic screen in glasshouse:** | 17.4 |
| **Unattributed:** | 218.02 |
| | |
| **Total** | 895 |

The labour use range for all production tasks in Holland (provided by growers) varied from below 750 hours to approximately 900 hours for conventional production systems, and from just above 900 to over 1,400 hours for high wire systems. Consultants claimed that conventional crop figures could be as low as 600 hours for two crops where the glass remained empty (or was filled with another crop and thus not allocated to cucumbers) during the winter, through 700-750 hours for efficient production at lower yield levels to above 1,000 hours for the highest production.

One of the factors governing the number of crops grown per season in Holland is the amount of "domestic" yield (class II or lower). This is in the order of:

| | |
|---|---|
| Two crops | - up to 10 kg/m$^2$ |
| Three crops | - up to 4 kg/m$^2$ |
| Four crops | - up to 2 kg/m$^2$ |

The production range in Holland is between 50 and 90 kg/m$^2$, with the majority between 65 and 73 kg/m$^2$. By contrast, the production range for the UK is from below 50 to 75 kg/m$^2$, with the majority between 52 and 68 kg/m$^2$ (NB - UK yields do not normally include the "domestic" grade included in Dutch figures).

## Conclusions

The labour use range in the UK for conventional production of long season cucumbers varies from 750 hours to above 1,150 hours (excluding grading and packing), indicating a wide variation in the efficiency of the systems used. However, this has to be seen in relation to the block size - or more correctly the row length. One UK nursery with a range of row lengths (and block sizes) has a labour use range from 925 to 1,060 hours. This indicates the potential for labour reduction just by reducing "row end" activities. This change can obviously only take place when re-building but it should be taken into consideration.

This increase in row length is taken to full advantage in Holland where much re-building is taking place due to re-location or just re-investment on existing sites and row lengths. The optimum length is considered to be about 100m.

UK production uses more labour - both from the point of view of per unit area and per unit of production. This is slightly off-set by the reduced costs of labour in the UK but it does need to be addressed.

UK growers need a system of recording specific labour activities similar to that taking place in Holland so that they can compare their labour use with other growers. Some UK growers are still reluctant to make these comparisons - either because they will give away money saving ideas or possibly because they know that their present systems are in-efficient. The weekly production comparison currently being used by 15 sites through the Cucumber Grower's Association will provide the basis for a more meaningful comparison of production costs including labour use.  However, more details of the actual jobs being carried out by that labour must be recorded.

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