Grower Summary

CP 085

Securing skills and expertise in crop light responses for UK protected horticulture, with specific reference to exploitation of LED technology (EMT/HDC/HTA Fellowship)

Annual Report 2016

Horticultural Fellowship Awards

Interim Report Form

Project title:	Securing skills and expertise in crop light responses for UK protected horticulture, with specific reference to exploitation of LED technology (EMT/HDC/HTA Fellowship)
Project number:	CP85
Project leader:	Dr G M McPherson, STC
Report:	Annual report, Year 4, Nov 2016
Previous report:	Annual report, Year 3, Nov 2015
Fellowship staff:	Dr Martin McPherson, Science Director, STC (lead Fellowship mentor) Prof. Nigel Paul, Lancaster University (Mentor)
(“Trainee ”)	Dr Phillip Davis, Applied Photobiologist, Dr Rhydian Beynon-Davies,
Location of project:	Stockbridge Technology Centre
Industry Representatives:	Chis Plackett, FEC Russel Woodcock, Bordonhill James Bean, Crystal Heart Salads Neal Wright, Micropropagation Services Simon Budge, VHB Ltd (Herbs) Colin Frampton, Consultant Steve Carter, Protected and indoor Ornamentals Geoffrey Smith, Mapleton Growers (Protected Edibles - Lettuce)
Date project commenced:	1 October 2012
Date project completed (or expected completion date):	30th September 2017

DISCLAIMER

AUTHENTICATION

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

Dr Phillip Davis
Project Manager
Stockbridge Technology Centre

Signature .... Date ....

Report authorised by:

Dr Martin McPherson
Science Director
Stockbridge Technology Centre

Signature .... Date ....

Progress Against Objectives

Objectives

Training

Objective T1. To provide the Fellow with the knowledge, understanding and practical skills to undertake applied plant science in the area of plant light responses, lighting and cladding materials.

Objective T2. To establish the Fellow with a network of contacts within the major commercial producers of horticultural LEDs (and cladding plastics).

Objective T3. To establish the Fellow with a network of contacts in the science base in fundamental and applied plant photobiology in Europe and beyond.

Objective T4. To provide the Fellow with a solid appreciation of the "business basis" for horticultural R&D, including aspects such as staffing, costings and the range of possible funding routes.

Objective T5. To establish the Fellow with a network of contacts with experts from the industry, including applied horticultural consultants currently active in supporting UK protected cropping, and through their respective technical groups, representatives of the major protected cropping sectors in the UK.

Objective T6. To expand the training objective of the fellowship program enabling Dr Davis to train other members of the team at STC. Much of this training will be given to Dr Beynon-Davies.

Research

Objective R1. For the fellow to undertake an initial, objective review of current developments and progress in lighting technology with support from the leading manufacturers and including a brief fact-finding tour overseas.

Objective R2. To objectively assess the properties of a selection of LEDs currently available or proposed for use in UK horticulture in terms of total irradiance (intensity), spectrum, efficiency and response to dimming.

Objective R3. Based on R1 and R2 to identify gaps in current scientific knowledge with respect to crop responses (using existing Arabidopsis light response knowledge) to LEDs relevant to UK production and to undertake pilot-scale experiments into the responses of selected UK protected crops (particularly leafy salads, ornamentals & herbs) to LEDs found to have useful properties in R2. Information obtained under R3 will identify the potential of appropriate lighting systems for specific UK crops. The knowledge gained will be used to design further R&D studies, subject to additional external funding, for future commercial implementation in the UK (See Objective R5).

Objective R4. In addition to the Fellowship reports, to produce (i) a technical review of the "state-of-art" of LED lighting in Horticulture, (ii) an article in HDC News summarising the results of the Fellowship and the current status of LED lighting in horticulture and (iii) to participate in a programme of visits, workshops and conferences for growers, including those at the new STC facility.

Objective R5. This fellowship is intended as being a major element in securing long-term R&D in to LEDs (and other light-based approaches to production) in UK horticulture, but does not in itself deliver a major "stand-alone" research programme. HDC is currently undertaking a major assessment of future priorities for UK-based LED research, and while the outcome of this review remains uncertain, we anticipate that, based on progress during the fellowship and other projects, the Fellow will be taking the lead in preparing applications for funding to extend R&D in LED lighting in the UK, with the Fellow as the lead investigator.

Objective R6. In the current research environment there is a growing need to increase collaboration between organisations like STC, Universities and industry. In order to develop links with Universities it is necessary to further develop my scientific credentials through publication of our research in academic journals. This will both boost awareness of our research in academic circles but also demonstrate our scientific expertise in a manner that can be quantified.

Objective R7. The skills necessary to acquire project funding and run lighting projects are currently in development under objective R5 and through management of the AHDB funder research project 'Understanding crop and pest responses to LED lighting to maximise horticultural crop quality and reduce the use of PGRs' CP125. However, this program will be expanded to encompass development of collaborative projects with Universities and companies both with in the UK and as part of EU projects. Developing collaborative projects will require increased interactions with the network of contacts developed in training objectives T2-T5.

Objective	**Original Completion Date**	**Actual Completion Date**	**Revised Completion Date**
Objective T1.	December 2012	December 2012	
Objective T2.	December 2013	This is an on-going exercise as new	September 2017 and beyond.

		companies move into the area.	
Objective T3.	December 2013	Trainees have made many contacts across the industry and this will be an ongoing exercise.	September 2017 and beyond.
Objective T4.	December 2013	This process will continue throughout the fellowship	September 2017 and beyond.
Objective T5.	December 2013	This process will continue throughout the fellowship	September 2017 and beyond.
Objective T6	September 2017	Dr Davis is training Dr Rhydian Beynon Davies on use of LED lighting for crop production.	September 2017 and beyond.
Objective R1	December 2013	February 2013	-
Objective R2	January 2013	March 2013	-
Objective R3	December 2013	-	
Objective R4	December 2016	August 2015 and ongoing	
Objective R5	September 2017	Dr Davis is building links with several UK Universities.	September 2017 and beyond.
Objective R6	September 2017	Dr Beynon Davies have made contact across the industry.	September 2017 and beyond.

Summary of Progress

In its fourth year this Fellowship has continued to progress well and a substantial amount of knowledge has been gained regarding plant light responses as well as the economic implications that LED lighting systems have on the industry. Dr Davis has learned more regarding the spectral qualities of removable glass coatings. Dr Beynon-Davies has gained knowledge of soft fruit production under LED lighting.

Training objectives

Objective T1.

Competed year one.

Objective T2.

During the fourth year of the Fellowship Dr Davis has remained in contact with the multiple LED manufactures and tracked the changes and advances that have happened in the field. LED lights are gradually becoming more energy efficient though the spectra of the lamps have remained similar. More companies are attempting to move in to the Horticulture sector but in many cases these new entrants make similar mistakes due to a lack of plant knowledge. LED companies that have been working in horticulture some several years are investing in developing their understanding of crop responses to LED light. The work running in the AHDB Hort. Funded project CP125 has provided multiple opportunities for Dr Beynon-Davies to develop his understanding of plant light responses.

Dr Davis has learned about the range of removable glass coatings by visiting and performing measurements at the ADHBs Pot and Bedding Plant Centre collaboration with Jill England at ADAS.

Objective T3.

During the third year of the fellowship Dr Davis has remained in contact with a wide range of scientists around the world and is following their work on LED lighting systems. Through these contacts Dr Davis has been invited to be a Subject Editor for the open access Journal Frontiers in Plant Science. This will not only help Dr Davis remain up to date with the latest research but will also help grow his profile an reputation in academic research circles.

He continues to co-supervise a PhD student at York University whom is examining the role of the circadian clocks in abiotic stress responses. He is also a co-supervisor of the new PhD student on the “CP 164 SPECTRA: Whole plant spectral response models” at Lincoln University alongside Prof. Simon Pearson.

Objective T4.

During the fourth year of the fellowship Dr Davis has continued to manage the CP125 and the high-wire tomato project in STC LED4CROPS high-wire facility. These projects have helped him further develop his man and time management skills. Dr Davis has continued to work with a range of different contacts to examine routes to bring in new collaborative projects and explore different routes for funding projects especially EU projects.

Objective T5.

Dr Davis has been developing links with in the N8 university group to increase the potential for collaborative research with UK Universities. All these efforts will help bring new technology and techniques to the industry. In addition STC has become a core member of the new Crop Health and Protection (CHAP) innovation centre which will help create many new opportunities to novel lighting projects. Dr Davis has been involved in several discussions as to how lighting can be involved in collaborative projects.

Objective T6.

The additional training provided to Dr Beynon-Davies has allowed him to make industry contacts and develop collaborative R&D projects which he has managed from start to finish.

Research Objectives

Objectives R1 & R2.

While the initial goals of these objectives have been completed further progress has been made in these areas. Continued contact with various LED manufactures and involvement in the CP139 project has allowed Dr Davis to remain abreast of advances in the LED technology.

Objective R3.

Results from the CP125 project continue to develop our knowledge and understanding of plant light responses. The research is now examining how blue and far-red light responses interact. The aim is to produce compact plants with advanced flowering.

Objective R4.

A technical review of LED lighting systems has been completed and published by AHDB.

Three articles have been published in the AHDB grower magazine summarizing some aspects of the LED technical review and the CP125 year on report.

Dr Davis has made several presentations at academic and grower facing events.

Objective R5.

The funding secured for the CP125 project has created many interesting results and will continue to do so for the remainder of the project. A major focus of the final year of the Fellowship will be combining information developed as part of CP125 and CP139 to perform analyses of the economics of LED lighting systems.

Objective R6.

A peer reviewed review-paper has been accepted for publication in the Journal Energy and Food security. We are also preparing 3 additional publications (one on lettuce morphology, one on morphology and flowering petunia, one on basil growth and photosynthesis) based on the results generated as part of this fellowship and work associated with CP125.

Objective R7

Dr Davis has been included as a collaborator on new project titled "Optimising site-specific solar radiation modelling for its application in the horticultural, agricultural and photonics industries" that is funded by Academy of Finland.

During this year Dr Davis has attended several meetings in Europe to expand his network of contacts and with the aim of being involved in new international funded projects.

Dr Davis has been included on an EU H2020 funding bid, this bid is still pending. While these activities have been successful (STC are involved in three large EU funding bids) the recent BREXIT vote has resulted in some uncertainty as to how we can remain involved in future funding opportunities we will, however, continue to build our contacts to remain involved where possible.

Milestones not being reached

None

Do remaining milestones look realistic?

Yes.

Training undertaken

Dr Davis has trained Dr Beynon-Davies on the methods and approaches for examining plant responses to LED lighting and how to perform applied research projects.

Conferences attended

Innovate: Innovation in Greenhouses November 2015.

Sainsburys Farming conference December 2015.

AHDB Horticulture 'Manipulating light for Horticulture' January 2016, Speaker.

EUVRIN Founding meeting, Brussels, February 2016.

NCUB Food 4.0, London, April 2016.

Dr Beynon-Davies attended Green Tech.

Sainsbury's R&D corporate Breakfast, London, May 2016.

8th International Symposium on Light in Horticulture, East Lansing, MI, USA May 2016.

N8 Agri-food Launch, June 2016.

Fruit Focus, East Malling, July 2016.

FRUIT ATTRACTION, Madrid, October 2016, Speaker.

CGA/PTG event, October 2016, Speaker.

EUVRIN meeting, Brussels, October 2016.

Grower Visits

Yorkshire Botanical Limited, HNS, February 2016

Rothamsted, Research Sector, April 2016

Soft Fruit Panel Meeting, East Malling February 2016

AHDB Pot and Bedding Plant Centre, Baginton Nurseries, Ornamentals, August 2016.

Expertise gained by trainees

Dr Davis has continued to develop his understanding of crop light responses and is working to train Dr Beynon Davies in crop light responses, trial design and implementation.

Trainees have gained a great deal of information regarding tomato crop agronomy, the influence of lighting on tomato production as well as the economics of crop production under lights.

Dr Davis has gained knowledge of commercially available glass coatings.

Dr Rhydian Beynon-Davies received his PA1 qualification.

Dr Davis has gained further insights to the process of gaining funding from AHDB panels which will be highly valuable for gaining future projects.

Involvement in bids for EU funding has help Dr Davis' understanding of international collaboration and funding.

Other achievements in the last year not originally in the objectives

During this year we have gained knowledge and understanding of fertigation techniques for hydroponic crops. This information is important for ensuring crops are grown to the correct standard and that crop light responses are credible.

Changes to Project

Are the current objectives still appropriate for the Fellowship?

Yes

GROWER SUMMARY: Modelling light responses

Headline

Our understanding of crop light responses has progressed considerably. We now have sufficient data to begin developing models that can be used to describe those responses and to predict how plants will respond to novel mixtures of light.

Background

The influence of different light spectra on plant morphology has been measured and documented for several species as part of the parallel CP125 project. These measurements have greatly improved our knowledge of crop light responses but alone they only provide examples of how plants respond to the light environment under which they were grown. In order to gain the greatest benefit from the measurements it would be useful to generate models that can predict how plant morphology changes with light intensity and quality. Such algorithms could be put to several different uses. For example to design light treatments to produce plants with specific size and morphologies (this has direct relevance to growers), to quantify the sensitivity of different crop species and varieties to different regions of the light spectra (this information could help growers select varieties that will perform well under their conditions but also has potential applications in crop breeding), or to test fundamental aspects of plant responses (this has the potential to identify new applications for spectral manipulation).

In this piece of work we have developed an algorithm that can be used to describe, understand and predict plant morphological responses to any mixture of red, blue, green and far-red light. The algorithm was parameterised to create a model of lettuce leaf length.

Summary

Based on our knowledge of plant light responses we generated five hypotheses aimed at describing the influence of light on lettuce leaf length:

1) There is a theoretical 'dark-leaf-size' (L_D) which is the length a leaf would grow in darkness if there was no resource limitation to growth.
2) Increasing blue light intensity provides a restriction (R_B) to leaf growth.
3) Increasing red light intensity provides a restriction (R_R) to leaf growth.
4) Increasing green light intensity reduces the restriction (R_G) to leaf growth.
5) Increasing far-red light intensity reduces the restriction (R_F) to leaf growth.

Each hypothesis was modelled with a non-linear equation assuming each response saturates at a given light intensity. The five parameters were combined to produce a single algorithm that would describe leaf length (L):

$$L = L_D - (R_B - R_G + R_R - R_{FR})$$

The model shows that the shortest leaves would be produced in light treatments containing between 40 and 90 % blue light. The model indicates that only 8 µmol m_{-2} s^{-1} of red light is sufficient to provide the maximum red light restriction on leaf length but that 40 µmol m_{-2} s^{-1} of blue light is required to provide the maximum restriction on leaf length.

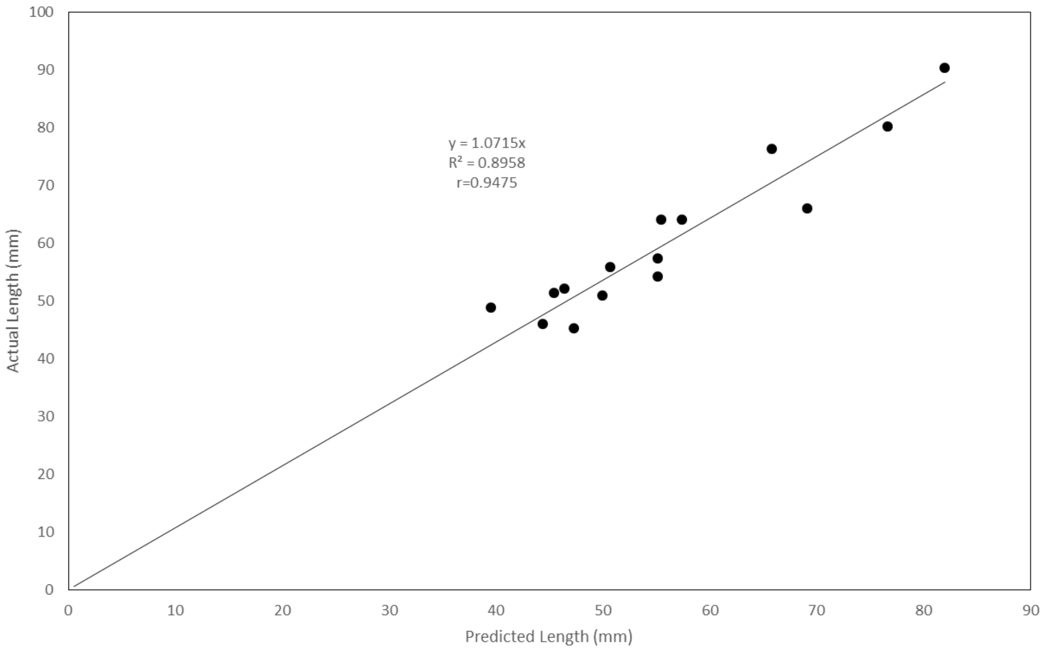

Figure 1. The validation of the leaf length model when parameterised for the Alega lettuce variety. Each data point represents the mean length of at least 8 leaves.

These models are expected to need refinement as more measurement conditions (for example no UV light treatments have been included so far), morphologies (different plant organs could respond differently) and species are tested but they have proved successful when tested against this leaf length data set. This modelling approach could be used to design light treatments that will produce lettuce plants with specific characteristics a key step in making the best use of LED lighting systems. The models will now be tested on other measured plant light responses, such as internode lengths. Ongoing development of the model will enable application to a wide range of plant responses. This work will feed in to the new ADHB funded studentship CP 164 - SPECTRA: Whole plant spectral response models.

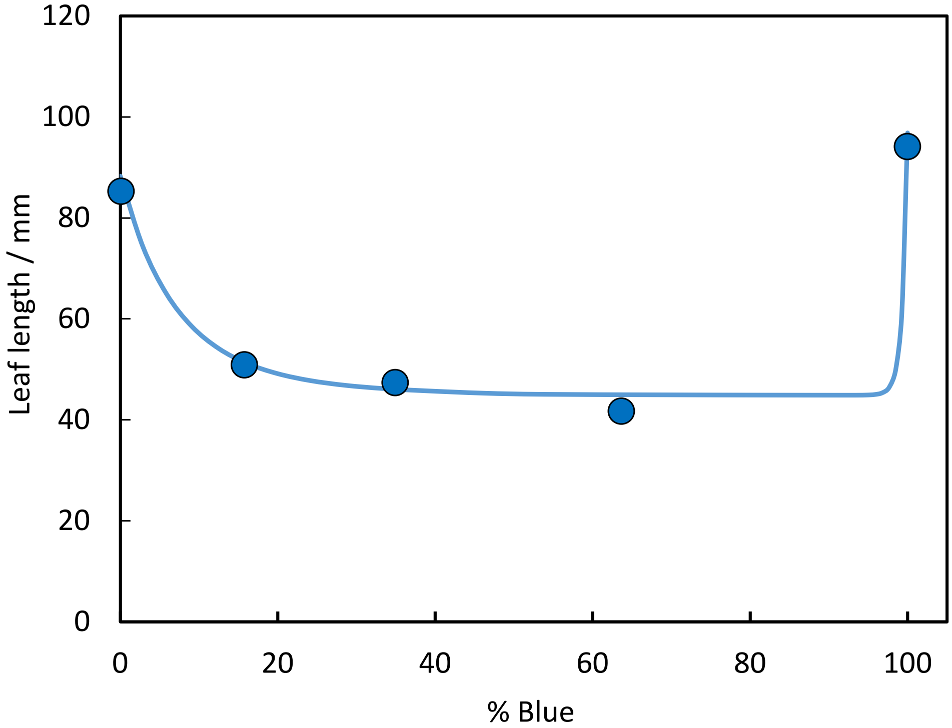

Figure 2. The leaf length of lettuce plants grown under light spectra containing different mixtures of red blue light. Circles indicate the mean measured value from 30 leaves and the line represents the model prediction of leaf length under any red: blue light mixture.

Financial Benefits

The procedures reported here provide the first steps in generating a whole plant model that describes plant morphological responses. Currently the model needs further development before it can be used in systems beyond lettuce leaf length. However, in the longer term the ability to model and predict plant light responses will help growers determined which lighting systems will be most likely to meet their needs. Given that LED lighting systems are expensive to install (£400,000 or more per hectare depending on the light level and type of installation) and that they have a significant influence on plant growth, morphology and quality it is important that the most appropriate lights are installed. Initially the models will help refine the range of light treatments required during scoping of different LED systems and any necessary R&D, reducing costs. Eventually the modelling process will be sufficiently accurate to select/design lighting systems for any crop in any situation. The models also hold the potential to allow decision support capabilities. For example sun light measurements could be supplied to the model to help growers to decide when lights need to be turned on, or if plant growth regulators should be applied. This could help reduce running costs, minimise the use of PGRs, improve plant quality and consistency thus reducing wastage. Even with the 30% energy saving LEDs provide compared to HPS lighting systems can still be expensive to run (with a light intensity of 100 μmol m^{-2} s^{-1} and an energy price of £0.09 kWh^{-1} it would cost ~£400 to light one hectare for 12 hours). Assuming the light spectra is correct plant quality will be improved by lighting production areas but better control of lighting systems will help ensure the benefits are not out weighted by the costs.

Action Points

Due to the early stage of this work the models currently have limited applications. This work will contribute to the PhD studentship program 'CP 164' that will aim to develop models with a wider scope and range of applications. If any growers or lighting manufacturers are interested in supporting or making use of this work they should contact Dr Davis as the models could be adapted for specific purposes to hasten their impact.

GROWER SUMMARY: Glass coatings (AHDB Pot and Bedding Plant Centre)

Headline

Trials at the AHDB Pot and Bedding Plant Centre at Bagintons Nursery are examining the durability of a range of glass coatings provided by several manufactures. The measurements performed in this work provide additional information on the performance of these coatings by examining how they influence the light spectrum/quality.

Background

Glasshouses are designed to maximise light transmission while minimising the effects of solar heating (taller glasshouses reduce the rate of solar heating). However, the large differences in light that occur through the seasons means that crops can receive too much light and heat in the summer and not enough light in the winter. Removable glass coatings provide a flexible method for altering the spectral properties of glasshouses through the seasons. At the AHDB Pot and Bedding Plant Centre a range of glass coatings are being trialled for durability and ease of use. Here we report on how the different coatings influence the light transmission spectra as well as the total amount of light.

Summary

Coatings designed to diffuse light (ReduFuse, D-fuse, Optifuse) or to provide shading (Eclipse, ReduSol, Q3 and Q4) were observed to have little influence of the spectrum of transmitted light but did change the total amount of light that was transmitted (Figure 6). All products were observed to diffuse light, though these measurements were designed to assess shading and spectral effects rather than to quantify the extent of diffusion (Haze factors). Products designed to reduce the solar heating caused by the sunlight (Q Heat, TransPAR, ReduHeat) were observed to reduce the transmission of light with wavelengths greater than 650nm (so they reduce transmission of the red region of the PAR spectrum) and to reduce the transmission of UV light, wavelengths shorter than 400nm. The reduction of UV transmission may have little impact of crop performance when used on glass structures because glass also absorb UV light (glass removes 50% of light with a wavelength of 350nm and blocks the majority of light below 300nm) but may have greater effects if used on structures constructed from UV transmitting plastics. The products produced by the different manufactures were observed to have similar light transmitting qualities. The measured transmittance values were found to be very similar to those reported by the manufactures.

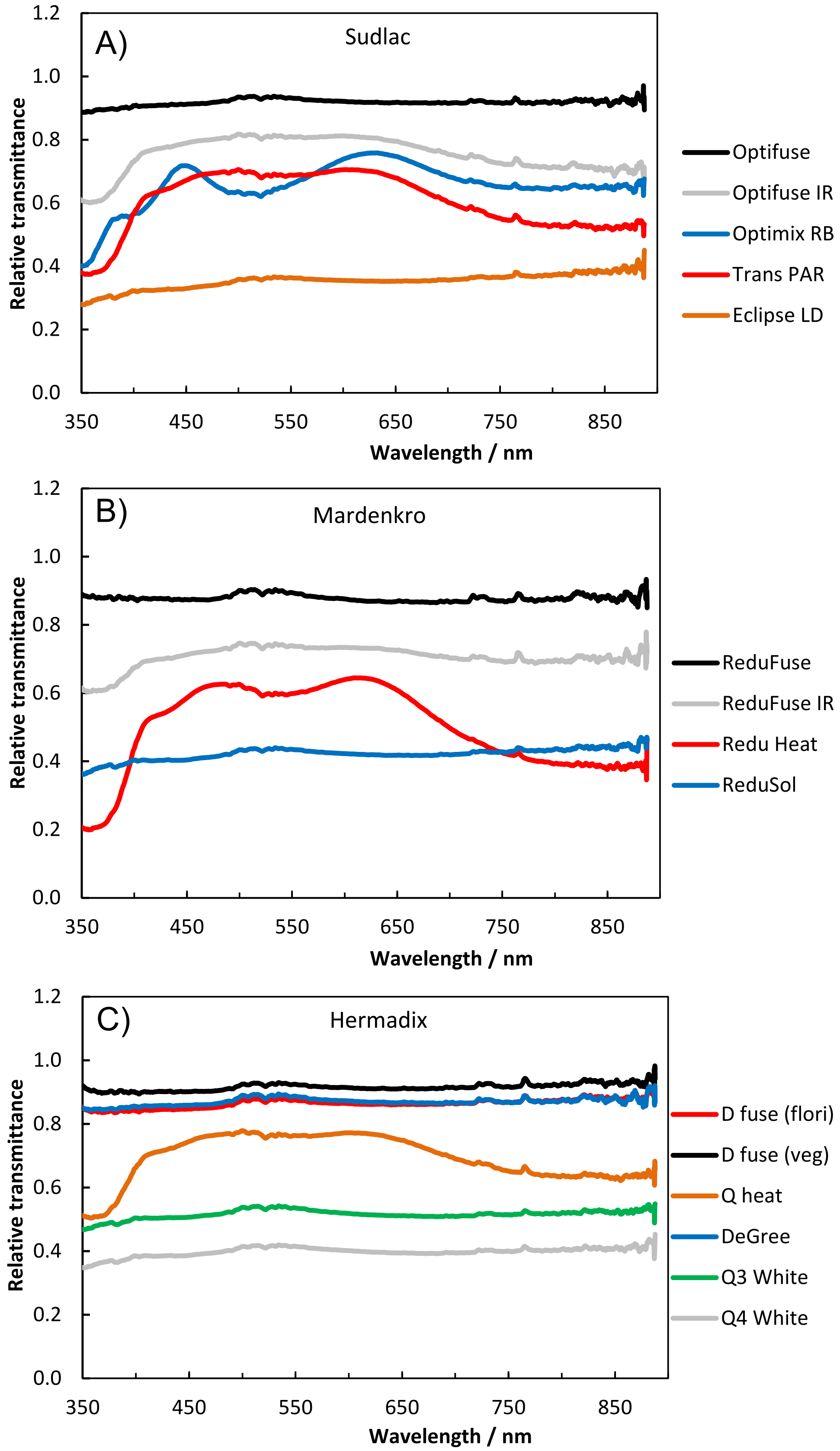

Figure 6. The relative mean transmission spectra of the different glass coatings. Spectra are grouped based on the manufacturer that produced the products **A)** Sudlac, **B)** Mardenkro

and **C)** Hermadix. Transmission spectra were calculated relative to the transmission of glass and so exclude the influence of glass.

Financial Benefits

These measurements will allow growers to make informed decisions when they choose which glass coating to use on their glasshouse. The data will help growers select a coating that meets their needs and compare the products produced by different manufacturers. When combined with the coating durability assessments that are ongoing at the AHDB Pot and Bedding Plant Centre, growers will be able to identify the most cost effective product for their situation and crop needs. With the cost of glass coatings ranging from between £540 to £5280 +VAT per hectare significant savings could be achieved by selecting a lower cost product that is able to provide the desired light environment. While shading is required for some scorch prone crops too much shading can reduce growth rates and may impact cropping schedules. These results show that if correctly followed the manufactures guidelines will results in the desired levels of shading. Further information on the durability and costs of the different coatings can be found in the AHDB Pot and Bedding Plant Centre - New product opportunities for pot and bedding plant growers (PO 019) reports.

Action Points

1. When planning to apply a glass coating growers should first define the reason for applying the coating (to diffuse light, to reduce light intensity or to reduce solar heating).

2. Determine the range of products that could be used to achieve those goals, the application rate required and the costs of the comparable products.

3. Determine the duration over which you will require the coating to last. For example according to the manufactures product information the two Hermadix products Q3 White and Q4 White can both be used to provide between 80 and 40% shading to a glasshouse, depending on the application rates (our results indicate that the manufactures guidance is accurate). However, at 45% shading the Q4 White coating could last to up to four weeks longer than the Q3 White coating due to its greater weather durability. The ongoing trials at the AHDB Pot and Bedding Plant Centre will provide useful information regarding the life span of the coatings included in the trials and in UK weather conditions.

4. When assessing the costs of a coating also ensure you examine the costs associated with removing the product at the end of the season.

5. Always follow the manufactures application instructions to ensure an even coat is applied throughout the glasshouse.

6. Following the application of any coating, crop performance should be monitored closely to ensure the crop is responding as desired.