Grower Summary

CP 164

SPECTRA: Whole plant spectral

response models

Annual Report 2020

Project title:	SPECTRA: Whole plant spectral response models
Project number:	CP 164
Project leader:	Prof. Simon Pearson
Report:	Annual report Year 2, 08/2020
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Key staff:	Gulce Onbasili (PhD student)
Location of project:	University of Lincoln
Industry Representative:	N/A
Date project commenced:	01/2017

DISCLAIMER

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

AUTHENTICATION

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

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GROWER SUMMARY

Headline

There might be an opportunity to reduce energy consumption and CO2 emissions for LED lit Controlled Environment Agriculture (CEA) systems by adopting the following:

- Identifying the right lighting recipe for selected crop
- Adopt DC rather than intrinsic AC power supply systems to feed LED lighting for plants; saving from grid AC to DC conversion losses occur at every lighting module
- Using LEDs at lower currents for increased efficiency and lifetime of the system
- Partially dim lights in conjunction with sunlight
- Consider use of renewables to supplement the grid power use

Background

Protected cultivation has developed rapidly worldwide to meet the increasing demand for fresh vegetable and horticulture crops. Greenhouses with supplementary lighting and plant factories are the most recent phases of modern protected horticulture. Artificial lighting systems can be used to improve the quality and quantity of agricultural products. The trend towards protected horticulture has several reasons such as, growing world population meanwhile declining arable lands leads to farming in smaller fields with bigger yields, increasing food demand, urbanisation problems which create overpopulated cities, food security issues which has been highlighted by a global pandemic, unsustainable pesticide and chemical usage in agriculture, water scarcity, fluctuating yield over the year, meanwhile the market demands all-year-round supply [1,2]. Optimisation of LED lighting systems has great significance for modern agriculture, as supplementary lighting in greenhouses or the sole light source in plant factories.

Summary

The overall aim of this research is to maximise energy efficiency of plant growth using LEDs for application in CEA, while also considering carbon footprint and cost. This involves firstly understanding how plants respond to different light and secondly, it involves understanding of LED device and whole artificial lighting system energy consumption. These are researched by both experimental and software/modelling-based methods.

Firstly, neural network analysis on LED lighting for lettuce was investigated with the aim of aiding the prediction of optimal light recipes. A series of data sets from various literature on lettuce growth using LEDs was collected and normalised such that the data was maximally compatible with each other and the experimental results from year 1's work to use as neural network input data. A deep neural network was then fitted to the data using MATLAB to test performance. Fitting results show that there is a general tendency for the neural network to fit to the target data, with an R value of around 0.8 for all data sets and an error histogram which is significantly better than one which would represent random prediction data. There is however significant variation in the error, with some large errors in neural network predicted verses target data. This was thought to be due to the incoherence between the different studies in the literature. Not only were many of the studies looking at different variants of lettuce, but they also had different experimental conditions and approaches beyond the lighting input data. As Ozawa *et al.* stated in their work comparing two studies with very similar conditions two years apart, there was significant different in output data even in identical lighting conditions for the same crop [58]. This shows that although neural networks could indeed prove to be very useful in predicting optimal light recipes, difficulty comes when collating data from different studies. If enough data on growth of a species under several LED light recipes was available from a single source with identical experimental conditions and procedure, fitting of data using neural networks could potentially give considerably better results.

Secondly, we investigated the theoretical basis for potential energy savings that can be achieved through improved lighting system design. The following CEA power saving considerations were investigated in a simplified conservative approach, which showed:

1. Energy saving from appropriate choice of the spectral recipes based on the literature. A comparison of purely white Osram LED boards vs an energy optimal [59] red/blue/white mixture with the same PPFD output value gives:

   A Calculated Energy Saving of **21%**

2. Calculations based on dimming LED boards during sunlight hours on clear days gives:

   A Calculated Energy Saving of **8%**

3. DC rectifier use in place of AC could increase efficiency and would be less likely to break since fewer components and therefore increase average lifetime of modules which provides:

   An Estimated Energy Saving of **10%**

4. Operating LEDs at half the forward current increases power output efficiency and will also lower LED junction temperature and therefore increase lifetime, while making the modules more compact by reducing heatsink requirements; so higher investment of LED number is balanced by energy saving and increased time before replacement giving:

   An Estimated Energy Saving of **6%**

5. Dynamic and model aided control of CEA light environment would allow efficient use of natural lighting to minimize energy use in supplementary artificial lights, as well as helping sole artificial lighting setups to grow plants.

These savings have been calculated to give a significant combined total estimated energy savings of approximately **38.5%** when compared with a system which doesn't employ any of the energy saving methods investigated. A costing analysis is ongoing.

Thirdly, the HOMER software, which is a piece of software used to model and evaluate possible designs for both off-grid and grid-connected power systems, was used with system input load requirements, energy cost tariffs and installation costs along with four different grid connected and off-grid supply setup regimes to investigate accurate geographical energy consumption and cost for electricity supply for a CEA system. A model system was built based on the strawberry growing facility at the University of Reading. My simulation results based on this model show that a grid connected system with wind installed would be the cheapest and most environmentally sustainable option, with a calculated capital cost saving of 5%, a levelized cost of electricity saving of 24% and a reduction of CO_2 emissions by 41%.

Finally, power distribution to lighting setup was considered. Arguments for DC grid supply in place of AC grid supply to LEDs were discussed, referring to existing literature on other DC grid application areas such as data centres, residential power networks and office buildings, which realise electricity and cost savings from the application of a DC grid. Schematics of a DC based greenhouse system were discussed followed by modelling of both DC-DC buck converter and rectifier coupled with buck converter in MATLAB Simulink. Full efficiency and power loss calculations are currently in progress.

Financial Benefits

The savings outlined in the summary have been calculated to give a significant combined total estimated energy savings of approximately **38.5%** when compared with a system which doesn't employ any of the energy saving methods investigated. A costing analysis is ongoing.

Action Points

Growers using LED CEA systems or LED supplementary light in a glasshouse can do the following to reduce energy consumption:

- **Careful choice of LED device model** – Efficiencies can vary significantly as demonstrated in the science section of this report (14% difference in energy consumption for same light output shown), the μmol/J gives indication of this efficiency.
- **Consider running LEDs at lower current** – This requires a higher number of lights operating to reach the same level of light intensity, but due to the higher efficiency at lower currents, running LEDs at half of the nominal current gives a 6% reduction in energy consumption. Also, lower currents significantly increase the lifetime of the LEDs which could compensate the extra cost of investing in more to begin with.
- **Using DC main rectifier + DC-DC converters to power all LED modules with DC electricity** – This eliminates the need for each LED module to include its own AC/DC converter and therefore electrical efficiency is increased, by an estimated amount of 10%. Additionally, fewer components means lower frequency of faults occurring therefore saving in cost of replacement.
- **Consider weather on a daily basis to dim the LED system appropriately** – This is estimated to decrease energy consumption by at least 8% for a 3-tier vertical strawberry growing greenhouse as setup at the UoR.

Consider variation of electricity prices throughout the day – By varying the start and end time of the photoperiod seasonally to minimise cost, 8.8% yearly cost saving is calculated (when in conjunction with dimming). For a solely LED lit system, cost saving calculated at **28%,** based on tariff electricity prices available for a standard UK supplier.

