Grower Summary

CP 125

Understanding crop and pest responses to LED lighting to maximise horticultural crop quality and reduce the use of PGRs

Annual 2016

Disclaimer

The results and conclusions in this report may be based on an investigation conducted over one year. Therefore, care must be taken with the interpretation of the results.

Use of pesticides

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Before using all pesticides check the approval status and conditions of use.
Read the label before use: use pesticides safely.

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Project title:	Understanding crop and pest responses to LED lighting to maximise horticultural crop quality and reduce the use of PGRs
Project number:	CP 125
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Report:	Annual report 2016
Previous report:	Annual report 2015
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Date project completed (or expected completion date):	30 June 2017

GROWER SUMMARY

Headlines

- Spectral manipulation using LEDs can be used to control plant morphology and flowering time.
- LED lighting can provide the optimal conditions for rooting cuttings.
- Lighting mother stock plants during the winter months increases cutting quality and strike rates.
- Early results indicate that light quality can be selected to maximise plant resistance to pests.
- Biocontrol agents can successfully identify pests under LED lighting in controlled conditions.

Background

The experiments reported here are arranged in three work packages.

Work package 1 - General agronomy under LED lighting

This work package will examine the general agronomic practices required for plant production under LED lighting. One of the major benefits of LED lighting is their low energy consumption compared to conventional lighting systems. Their robust nature and ability to rapidly turn on and off also provides the possibility of further reducing energy consumption by either creating mobile light rigs that move over the crops at regular intervals or strobing the light to reduce energy consumption. Both these techniques can lower energy consumption, but this comes at the cost of a lower daily light integral (DLI). The results from year one demonstrated that mobile and strobe lighting systems designed to reduce capital and electrical running costs had a negative impact on plant performance and quality. This was caused by the combined effect of a reduced DLI and reduced plant light use efficiency. The work reported here (year 2) will focus on furthering our understanding of the influence of constant light intensity on plant quality, growth rate and running costs. The growth of Petunias, Pansies and Lettuce were examined in this work package.

Work package 2 - Influence of light quality on crops

The experiments in work package 2 examine the responses of plants to different light spectra with the aim of improving our understanding of the diversity of plant responses to light and to help commercial implementation of LED technologies. WP 2 is divided into subsections examining different aspects of light quality on plant morphology. This report contains results from four subsections of WP 2:

WP 2.1b: Influence of red : blue ratio on plant growth.

WP 2.1c: Influence of red : far-red ratio on plant growth.

WP 2.1d: Red : blue : far-red light combinations.

WP 2.3: Improving cutting propagation.

Several species were examined (Petunia, Pansy, Lettuce, Santolina, Clematis, Iberis). Where appropriate, plants of the same species were grown simultaneously in multiple work packages. The results are reported in groups based on work packages.

Work package 3 - Light quality and its influence on pests

During the first year we examined the use of different colours of sticky traps on pest trapping efficiency. In this report we examine the influence of light quality on aphid and spider mite performance cultured on Lettuce, Verbena and Cucumber plants grown under different light treatments. The effectiveness of biocontrol agents was also examined under different light treatments.

Summary

WP 1.2 - Energy saving and daily light integral

In general increasing the light intensity resulted in faster growth, more robust and compact plants with earlier flowering. However, providing too much light leads to plant stress especially at the seedling stage and increased installation and running costs. It is important to achieve a balance between providing enough light for good quality plant material while minimising the costs to maintain a strong economic basis for production.

In these experiments 200µmol m^{-2} s^{-1} was enough light to produce good quality Pansies, Petunias (Figure GS1) and Lettuce plants (propagation stage). In all cases providing less light resulted in slower growth and lower quality plants and did not result in an energy saving when the additional time required to produce crops was included in the analysis.

Figure GS1. The influence of different intensities of light in growth of **A)** Petunias 26 days after sowing and **B)** Pansies 74 days after sowing.

Higher light intensities (280 and 360 µmol m^{-2} s^{-1}) resulted in faster production and higher quality Petunias and Lettuce plants with thicker more robust leaves. Petunia plants grown under the highest intensity flowered five weeks after sowing. In contrast Pansies grown under the highest light intensity flowered only marginally quicker than those grown under 200 µmol m^{-2} s^{-1} and were very compact. Also the Pansy seedlings grown under the highest light intensity performed poorly and lower numbers of good quality plug plants were produced.

In summary a light treatment with an intensity of 200 µmol m^{-2} s^{-1} provides a good starting point for plant growth under LED lighting. Increasing the light intensity can help produce more robust plants and may hasten flowering. The optimum light intensity will differ between plant species (sun plants will benefit from higher light intensities than shade plants) and based on the desired properties of the final product.

WP 2.1b - Influence of red / blue ratio on plant growth

The most energy efficient LED lighting systems contain predominantly red and blue LEDs (see AHDB CP 139). Red and blue light can efficiently drive plant photosynthesis and control morphology. In the year one trials we demonstrated how different mixtures of red and blue light influenced plant growth and morphology. Plants grown under 100% red or 100% blue light were etiolated and had poor overall quality. Growth rates were greatest in plants grown under red/blue mixtures containing 11-15% blue light. The most compact plants were observed under light containing about 60% blue light. These data demonstrate the potential to use light treatments to replace the use of plant growth regulators. During this year we have repeated the experiments on Lettuce three times to create a robust data set that can withstand more detailed analysis (to be completed as part of the parallel CP 085 Fellowship programme) and to demonstrate the consistency of plant quality grown under constant light conditions. The data (Figure GS2) demonstrate the contrasting influence of light quality on biomass and morphology. The data on leaf size from the three experiments was highly reproducible.

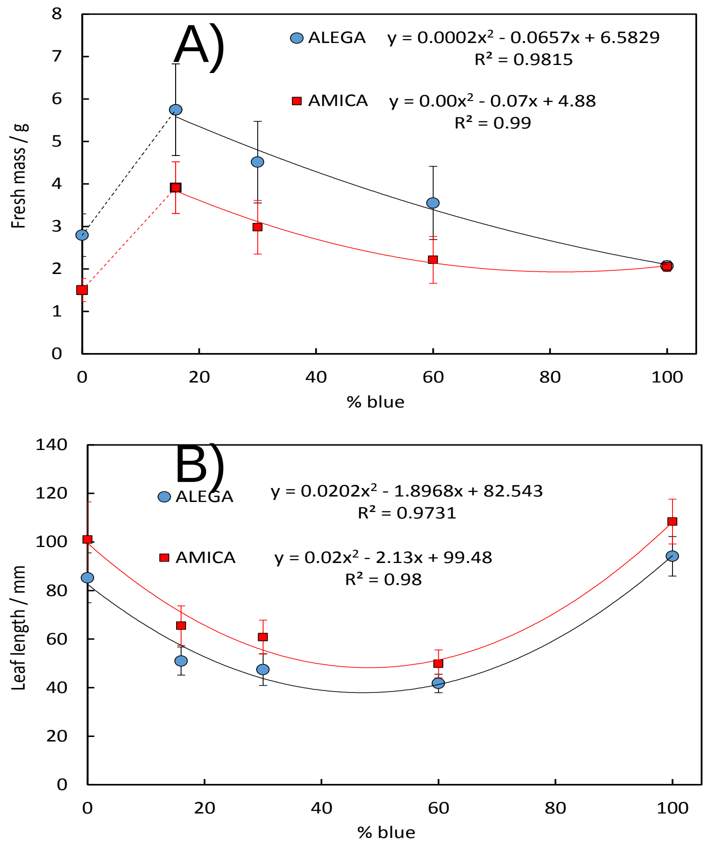

Figure GS2. Influence of blue light percentage on **A)** the shoot biomass and **B)** leaf length of two Lettuce varieties (Amica, a summer variety and Alega, a winter variety).

The influence of red:blue light spectra on Petunia flower development and flower size was also investigated in more detail. Flowers grown under light with 60% blue light were observed to open two days faster than flowers grown under 6% blue light (Figure GS3). Flowers that opened more rapidly were also found to remain open for a longer period, resulting in greater numbers of open flowers per plant.

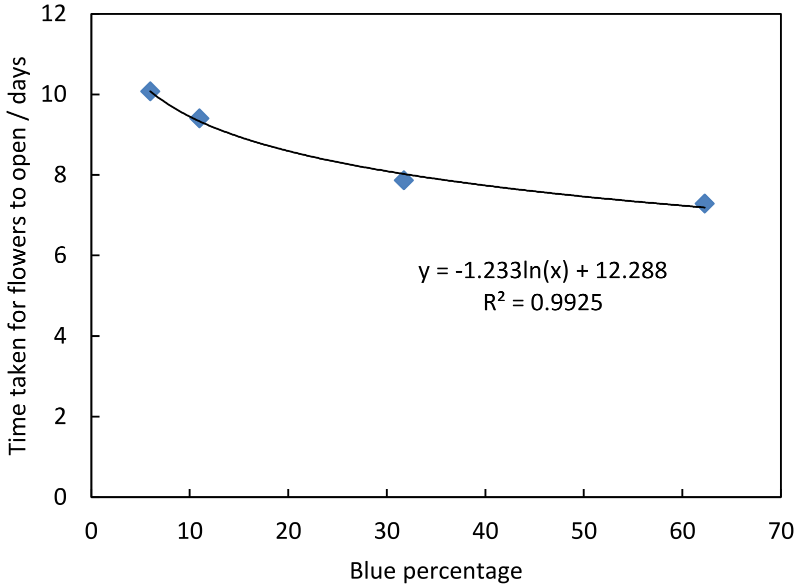

Figure GS3. Time taken for Petunia flowers to open when exposed to light treatments with different percentages of blue light.

WP 2.1c - Influence of red / far-red ratio on plant growth

The results generated in WP 2.1c in year one examined how different doses of far-red light influenced the growth of eight species (Basil, Sage, Cucumber, Lettuce, Petunia, Pelargonium, Pansy, Begonia). In general far-red caused plants to grow taller and flower though the magnitude of the responses differed considerably between species: Basil plants showed small responses to far-red light while Cucumber exhibited large responses. The experiments in WP 2.1c reported here have focused on generating a replicated data set in Lettuce. Far-red treatments were found to have a strong influence on leaf size. Altering the far-red light dose could be a useful method for manipulating plant morphology and appearance to enable crops to be grown to match the needs/preferences of end users.

WP 2.1d - Influence of high blue and far-red light treatments

The data generated in WP 2.1b and WP 2.1c described the benefits of red:blue (compact plants) and red:far-red (early flower) spectral manipulation. However, they also highlight the limitations of these manipulations. Red:blue manipulation can lead to slower growth and delayed flowering. Red:far-red manipulation can result in reduced pigmentation and plant stretching. This work package examines the potential to combine high blue and far-red treatments to produce compact plants that flower early. Petunia, Pansy and Lettuce were grown under eight light treatments comprising two red:blue mixtures (30:70 B:R and 60:40 B:R) each with four different intensities of far-red light (0, 11, 20 and 35 µmol m^{-2} s^{-1}).

The plant responses to red:blue:far-red combinations were consistent with the data from the other work packages. 30% and 60 % blue produced compact plants and far-red caused plants to stretch and induced earlier and more extensive flowering (Figure GS4). High-blue light treatments were unable to prevent the plant stretching caused by far-red light treatments. However, low intensity far-red treatments combined with high blue treatments were able to produce early flowering plants with less etiolation than would be the case for lower blue percentage treatments. In these experiments the best quality plants were produced under the 30% light blue treatments and the addition of far-red light advanced flowering by up to two weeks. The addition of greater than 11 μmol m^{-2} s^{-1} of far-red light had deleterious effects on morphology. Further light recipe development should focus on lower intensities of far-red light to identify a treatment that can induce flowering with minimal impact on morphology or short term far-red treatments that induce flowering but have little influence on morphology.

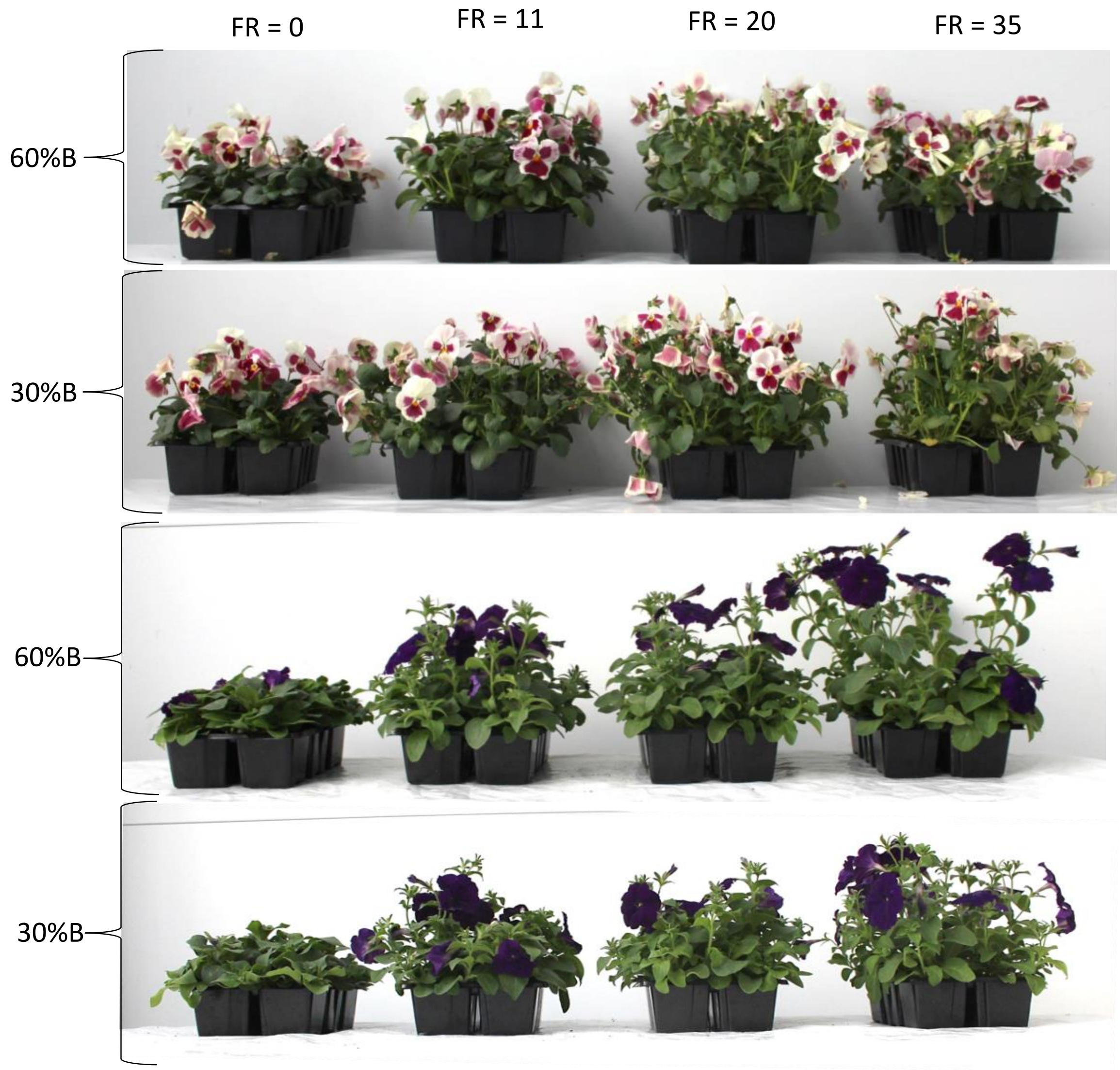

Figure GS4. Influence of red, blue and far-red light combinations on the morphology and flowering of Pansies and Petunias.

WP 2.3 - Improving HNS Propagation

Spectral manipulation of liners can improve strike rates. Reducing the amount of blue light in the spectrum, while providing sufficient light to maintain plant health and vigour, reduces cutting dehydration and greatly improves survival. This is particularly important during the first week after sticking. The light spectrum also influenced the speed and vigour with which roots developed. Maximum speed and percentage of rooting was achieved in treatments with little or no blue light (Figure GS5). 100% red, 90% red + 10% blue and a red:white treatment containing 9% blue resulted in the best rooting for Santolina 'Lemon Fizz', Clematis 'The President' and Iberis 'Absolutely Amethyst' cuttings. For Clematis, tip cuttings strike rates were on average 13% higher than for nodal cuttings but the influence of light treatments was similar on both types of cutting. Far-red light had a negative influence on liner quality and rooting success. The health of cuttings exposed to far-red light deteriorated more rapidly than those not exposed to far-red light. The amount of light provided to cuttings is also important for both cutting success and system economics. Too much light will stress the cuttings while too little light will weaken cuttings reducing the resources available for root growth. Santolina and Clematis nodal cuttings rooted equally well in 36 and 75 µmol m^{-2} s^{-1} of light, other species may benefit from higher or lower intensities.

Lighting mother stock plants through the winter months was shown to greatly influence cutting strike rate (Figure GS6). In this experiment the Santolina mother stock plants lit with 51 µmol m^{-2} s^{-1} of LED light produced cuttings with greater strike rates (70% rooted) than unlit (50% rooted) plants. Iberis cuttings also benefited from the supplemental light treatments though it was rooting speed rather than absolute strike rates that were improved. Ensuring light treatments are correct is also very important as incorrect lighting can reduce cutting survival. Santolina mother stock plants illuminated with low intensity night break lighting produced weaker cuttings with lower strike rates (~30% rooted) than unlit plants. It is thought that in this case the night-break lighting forced mother stock plants to grow, but the low natural light levels provided insufficient resources to maintain vigour resulting in weaker cutting material.

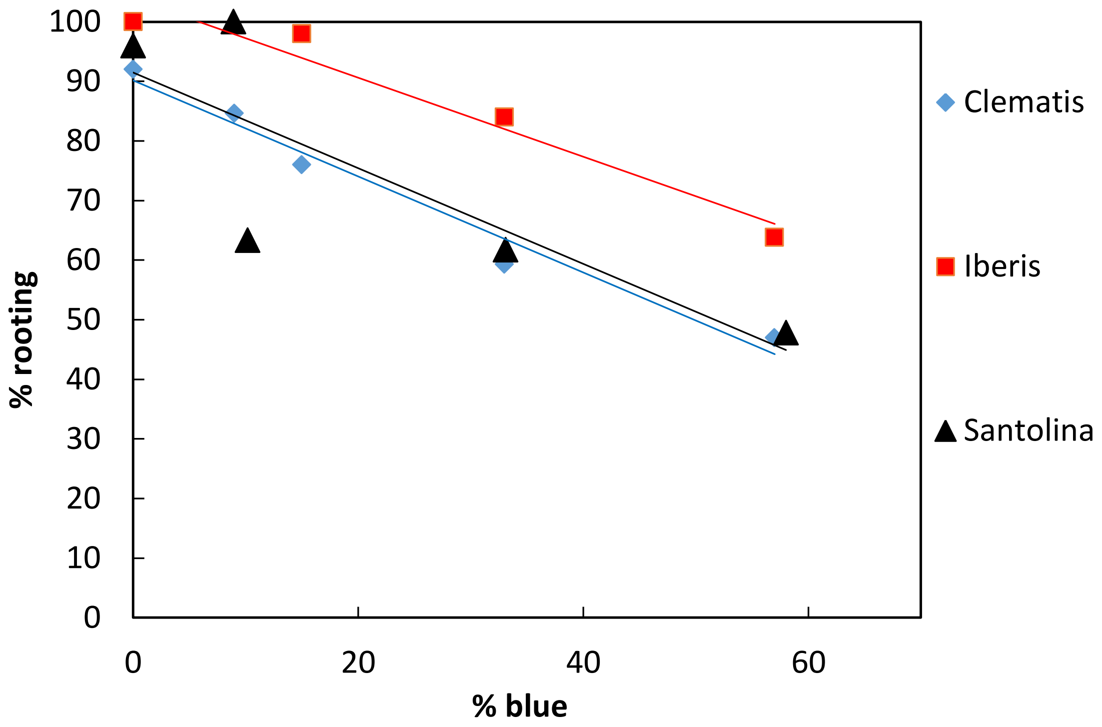

Figure GS5. The influence of blue light percentage of post-excision light treatments on Clematis (tip cuttings), Iberis and Santolina cutting strike rates.

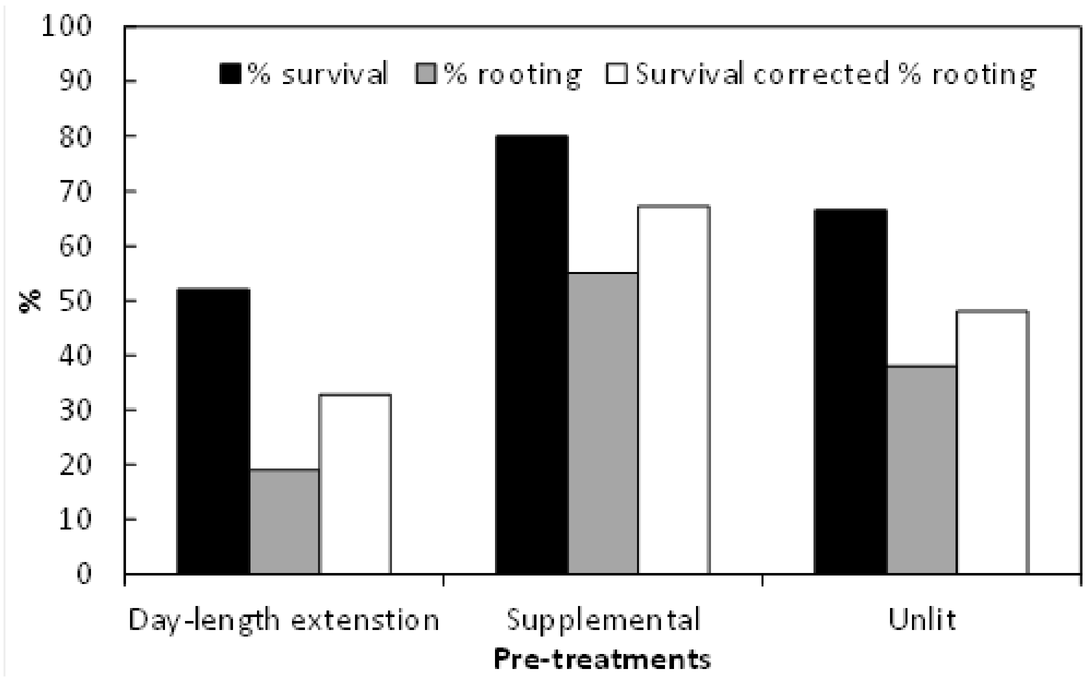

Figure GS6. The influence of pre-excision light treatment provided to the mother stock plants on the percentage of survival and rooting of the Santolina cuttings.

WP 3.3a - Determining the effects of plant physiology on Aphid development

During these experiments we encountered a number of challenges associated with culturing insects on plants grown under the LED lighting systems. Many of these challenges are thought to be caused by the light environment either via direct effects on the insects or indirectly via the plant light responses. While challenging from the perspective of performing experiments these difficulties are encouraging as they indicate that pest species would be expected to perform less well on LED grown plants and optimised lighting may provide some level of pest control.

When peach aphids were grown on Lettuce plants grown under different red:blue ratios aphid mortality was found to be significantly higher on plants grown under 60% blue light. This was thought to be associated with the aphids being unable to feed due to the physical characteristic of the Lettuce leaves (small compact leaves). When melon aphids were grown on Verbena (Figure GS7) aphids grew significantly less well on plants grown under 100% red light and significantly better under white light than on plants grown under red:blue mixtures. The leaves of Verbena plants have a curled morphology when grown under 100% red light and this may have influenced feeding. The white LED lights used generally produced a softer plant than red:blue light mixtures and this may have resulted in better aphid performance.

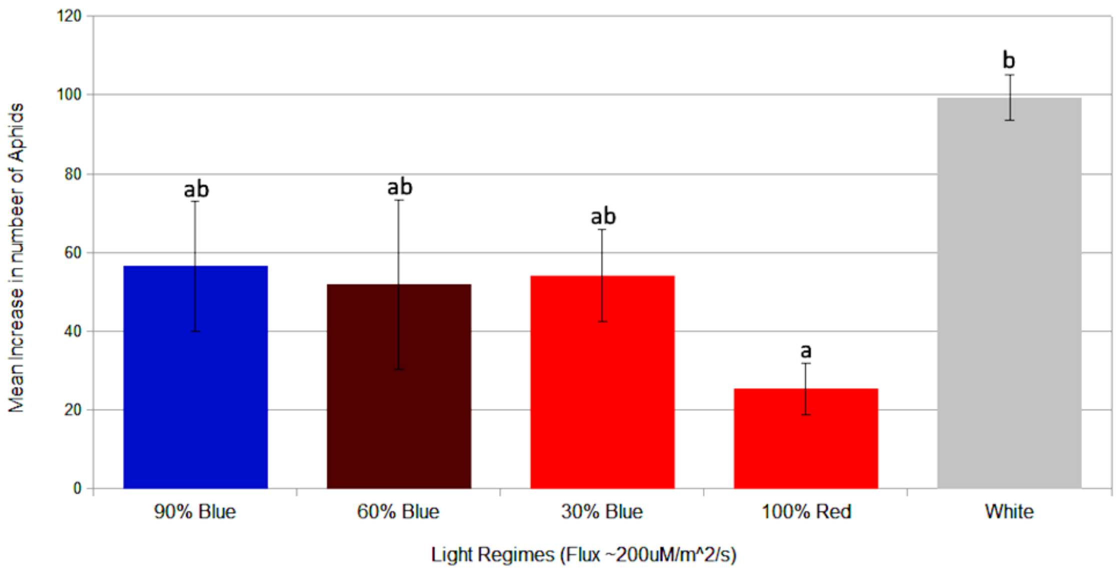

Figure GS7. Influence of light quality on melon aphid population growth on Verbena over a 10 day period. Error bars are standard error at n=6, and letters indicate significance groupings according to a TukeyHSD test ($p<0.05$).

WP 3.3b - Determining the effects of plant physiology on spider mite development

Spider mites were cultured on Cucumber plants grown under a range of red blue spectra as well as a white light mixture. Spider mite population growth was slowest under a light treatment containing 30% blue and 70% red light (Figure GS8). The populations grew most rapidly under 100% red and 90% blue,10% red light. This suggests that both red and blue light plant responses are involved in plant defence against spider mites.

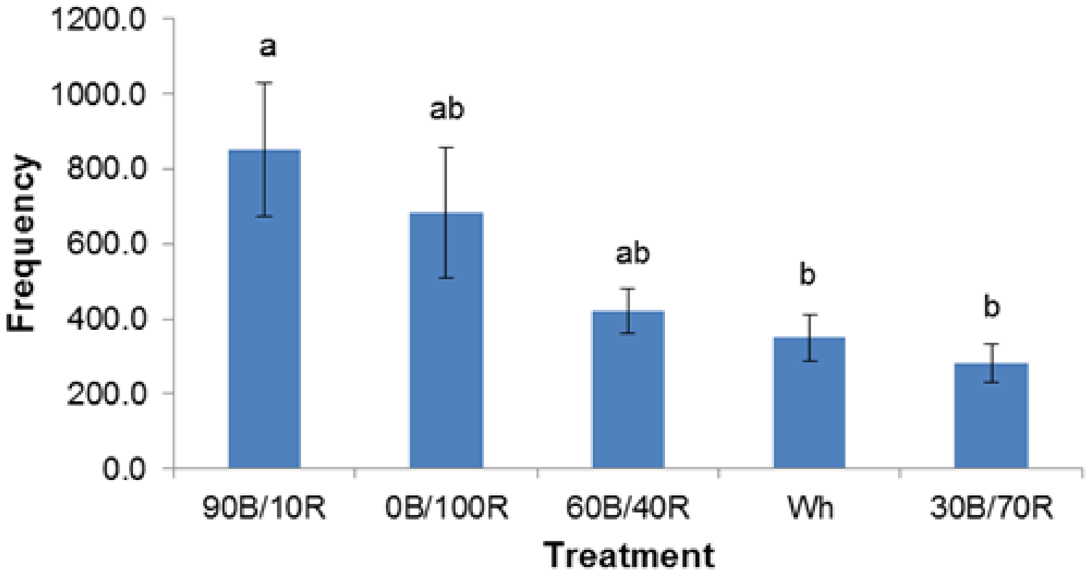

Figure GS8. Numbers of spider mite on Cucumber plants grown under light treatments with different red:blue mixtures. Error bars represent the standard error of the mean and Tukey's test significances. Letters above bars correspond to the results of the Tukey tests, where means not sharing a common letter are significantly different.

WP 3.4a - Parasitoid wasp activity

Biocontrol agents play a major part in pest and disease management programs and are likely to become increasingly important as regulations reduce the availability of pesticides. In non-controlled conditions our early attempts at using parasitic wasps in the LED4CROPS facility have resulted in no parasitism. It was unclear whether these attempts failed due to releasing too few predators or due the inability of the predators to effectively identify pests. In these experiments we investigated how effective parasitoid wasps (*Aphidius matricariae*) were as aphid biocontrol agents under red:blue light mixtures. When confined to the plants infested with aphids, in plastic bags, the parasitic wasps were able to identify and parasitize aphids. The greatest amount of parasitism was observed in treatments containing 30% blue light (Figure GS9). There were large differences in the amount of parasitism between the replicate trials that are thought to be associated with insect age.

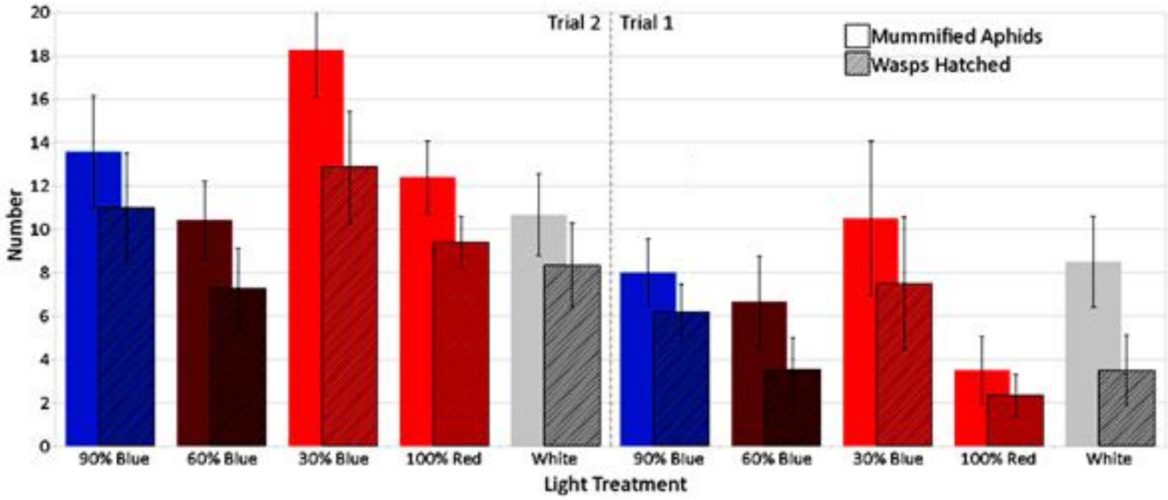

Figure GS9. Mean number of mummified aphids (solid bars) 10 days after exposure to two female wasps for 24 hours, and the number of new wasps (shaded bars) that had hatched from those mummies after a further 10 days. Data from two replicate trials are presented. Error bars are standard error at n=6 (Trial 1) and n=7 (Trial 2).

We also investigated if the light treatments influenced the activity of wasps during the illuminated period as differences in activity could be influencing rates of parasitism between treatments. Wasp activity was correlated with spectral quality of light with greater activity occurring under treatments with more blue light (Figure GS10). This is probably associated with the greater visual sensitivity to blue than red light.

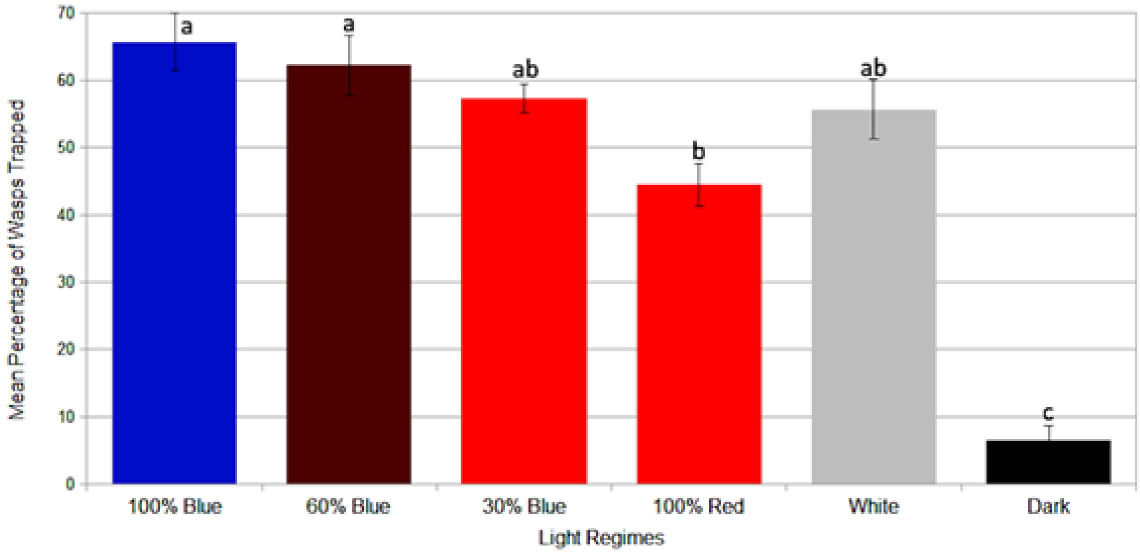

Figure GS10. Mean percentage of wasps caught in a colourless sticky trap only accessible by flight during a single 24 hour day/night period under different ratios of red and blue LED illumination, and in dark and white light. Error bars are standard error at n=8, and letters indicate significance groupings according to a TukeyHSD test ($p<0.05$).

Research Highlights

- Plant growth rate and quality increases with light intensity but maximum energy efficiencies were achieved at ~200 µmol m^{-2} s^{-1}.
- Plant growth rate was greatest under light mixtures containing ~10% blue light.
- Maximum growth regulation was achieved under light mixtures containing between 30 and 60% blue light.
- Far-red light can advance flowering by up to two weeks but has a negative impact on morphology.
- Careful selection of the blue light percentage and far-red intensity can be used to produce high quality plants with rapid flowering.
- Cutting strike rates were best in plants propagated under 100% red light.
- Lighting mother stock plants greatly improves cutting quality and strike rate.
- Pest performance appears to be inhibited by the LED light regimes used in these trials.
- The influence of light quality on pest performance differs between different pest-host combinations.
- Light quality also influences the effectiveness of biocontrol agents.

Financial Benefits

Advances in LED technology continue to improve LED energy efficiency with the newest systems achieving efficiencies of 2.8 mol J^{-1}, a 45% energy saving compared with 600W HPS lamps which have an efficiency of 1.92 mol J^{-1}. The economic benefits associated with these significant energy savings could become considerable as energy prices increase with time. The ongoing research and development in to design of LED lighting systems will be expected to keep the costs of LED units relatively high compared to HPS systems for some years, however, improved energy efficiencies will reduce installation costs as fewer units will be required to provide the same intensity of light.

The results in this report demonstrate that the ability to control the light spectrum with LEDs creates the potential to produce high quality plants and reduce the need for plant growth regulators. Cutting strike rates can be greatly improved by illuminating cuttings with spectra containing low blue and high red light proportions. Lighting mother stock plants through the winter months has the potential to further improve strike rates by maximising the quality of cutting material. These benefits potentially have greater impact on business economics than electrical energy savings.

The results from these trials provide the first steps in defining optimal lighting conditions for a range of crops. This information will help growers considering investing in LED installations and help ensure that light installations have the appropriate spectra for their crops. For certain crops there may not currently be a complete LED solution available. However, these data could help LED manufactures design lighting systems that meet the needs of different crops.

Action Points

To make use of most of the data generated in this report, growers would need to invest in LED lighting systems. Costs of lights and economic analysis of the benefits are beyond the scope of this report and will be unique to each business. However, these results outline the benefits provided by different regions of the light spectrum and how light intensity influences plant quality. These results will provide a baseline from which growers can begin to develop their own light treatments while performing small scale trials. It is recommended that small onsite trials are carried out before large scale investments are made. This is for two reasons 1) to ensure the light treatments are appropriate for the specific varieties being grown and 2) to help growers develop the appropriate crop management strategies (it is expected that LED lighting systems will result in altered crop water and heating requirements). At latter stages in this project more information will be provided to help growers learn how to manipulate crops with LED lighting.

The cutting rooting experiments indicate that light spectra have a large influence on strike rates. LED lighting systems can be used to greatly improve rooting efficiency of cuttings directly or indirectly if mother stock plants are lit. Propagation requires relatively low intensities of light so installation and running costs would be proportionally lower than for crop growth. If the installation of lights are deemed too expensive similar results may be achievable by using spectral filters that remove the majority of blue light.

For growers interested in using LED lighting we have roughly outlined the steps that should be taken to ensure a successful installation.

1. Identify the desired outcome of a lighting system *i.e.* improved crop quality, increased yield or reduced energy consumption.
2. Determine the lighting regimes required to achieve these goals and consider whether LEDs are required or if spectral filters can be used.
3. Conduct small scale trials to examine crop performance and learn how management strategies will need to be revised.
4. It is important to have accurate measurements of the light environment within a crop production area when performing lighting trials. LED lighting systems should not be measured using Lux meters. The best type of sensor for measuring LED lighting for crop production would be a PAR meter which measures the light that can be used by plants

for photosynthesis and makes measurements in units of μmol m^{-2} s^{-1} – for more information see the AHDB Horticulture technical guide ‘Lighting: The principles’.

5. Use the trial results to determine the economics of an LED lit production system