The use of light-emitting diode systems for improving plant propagation and production©

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INTRODUCTION

The propagation stage of plant production can be challenging but the quality of the resulting seedling, rooted cutting or young plant is crucial to the performance of the finished crop. In protected horticulture many aspects of the crop environment such as temperature, humidity and irrigation, are carefully controlled to optimise plant performance. However, despite the importance of light to the process, many propagation systems rely on solar radiation which varies through the season and from day to day, resulting in crop variability.

High pressure sodium and other types of high intensity discharge lamps have been used to provide supplemental lighting. While these can improve plant growth they can also result in stretching due to the lack of blue light in their output spectrum. The introduction of light-emitting diode (LED) lighting systems for horticulture caused great interest due to the potential energy savings compared with traditional lighting systems (LEDs use 25% less electricity than 600W HPS lamps for an equivalent light intensity). However, there is a growing body of evidence that suggests LEDs provide many additional benefits beyond simple energy saving that may have a greater impact on crop production, for example by being able to "tailor" the output light wavelength to meet specific crop management requirements.

PLANT LIGHT RESPONSES

To understand why the spectral control provided by LEDs provides an advantage it is first necessary to understand how plants sense and respond to light. Chlorophyll pigments absorb light energy at wavelengths between 400 and 700 nm during photosynthesis but plants also possess an array of other photoreceptors (light sensing proteins) that can detect specific colours of light, using this information to change their morphology in response to the light environment they are exposed to.

In dark or low-light conditions these photoreceptors are inactive and plants stretch (become etiolated) as they attempt to grow towards light. When exposed to light the photoreceptors are activated and drive a process called photomorphogenesis. During photomorphogenesis plant stretching is inhibited, the leaves open, turn green and bend towards the light. In addition to the morphological changes, many aspects of gene expression and biochemistry are altered that help plants acclimate to the light environment. Photomorphogenic processes function throughout the life of plants and help them acclimate to changing light conditions and also control the transition from vegetative growth to reproductive growth.

There are several types of photoreceptors each of which is responsible for a specific set of photomorphogenic responses though some responses, such as stem elongation, are regulated by several photoreceptors working together. The photoreceptors can, in general terms, be grouped by the wavelengths or "colours" of light to which they are sensitive, blue, red/far-red and UVB ("ultra-violet") light.

Blue light photoreceptors include the phototropins and cryptochromes. The phototropins control stomatal opening, phototropism (bending to towards the light), chloroplast movement within cells, leaf flattening, and inhibition of hypocotyl elongation. The cryptochromes are involved in regulating pigment synthesis, the circadian rhythm, flowering, and inhibition of hypocotyl elongation.

Red and far-red light are sensed by a family of photoreceptors known as the

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phytochromes. They function to help plants detect the red:far-red ratio which changes when, for example, taller plants grow above, and cast shade on, shorter ones; and at sunset. They are important for germination, inhibition of hypocotyl elongation, apical hook straightening, leaf expansion, flowering time, regulating circadian rhythms, and chlorophyll biosynthesis.

The UVB light receptor is known as UVR8 and is very sensitive to small amounts of UVB. UVB causes plants to produce more pigmentation and tougher, more robust, leaves (Wargent et al., 2009), and can increase the concentration of essential oils in herbs (Kumari and Agrawal, 2011; Hikosaka et al., 2010).

EXPERIMENTS USING LEDS IN PROPAGATION

With LED lighting it is possible to select the colour and intensity of specific wavelengths of light used for plant production. This means that the light output spectrum can be altered to stimulate the different groups of photoreceptors in the plants in a crop and this allows plant morphology to be manipulated to produce plants that match customer specifications. The light spectrum can also be selected specifically to improve important stages of crop production.

Cuttings are often challenging to propagate as they are prone to dehydration. Selecting a light spectrum to minimise dehydration can improve cutting propagation. In the LED4CROPS experimental facility at Stockbridge Technology Centre, Yorkshire, UK, *Elaeagnus*, *Photinia*, and *Rhododendron* cuttings exposed to 100 µmol m^{-2} s^{-1} of light with different red:blue light mixtures (100% blue; 64% blue:36% red; 35% blue:65% red; 11% blue:89% red; and 100% red) showed a marked decrease in survival as the proportion of blue light in the spectrum increased (Figure 1). This effect was particularly pronounced in the *Elaeagnus* cuttings which shed most of their leaves within 2 weeks of exposure to 64 and 100% blue light mixtures. As blue light is associated with stomatal opening, higher intensities of blue light are thought to be causing cutting dehydration. Cuttings survival was best in light mixtures containing between 11 and 35% blue light.

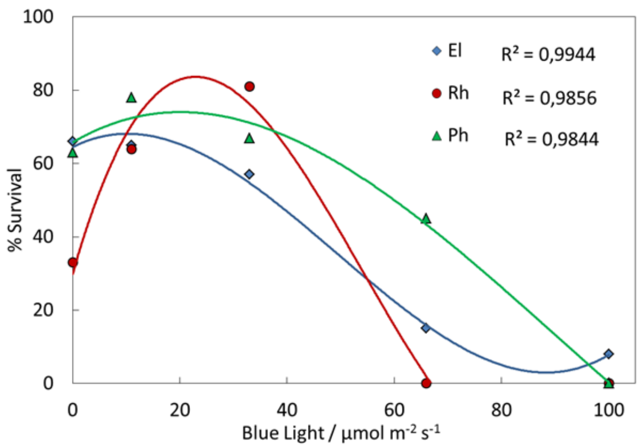


Figure 1. The percentage survival of *Elaeagnus* (El), *Photinia* (Ph), and *Rhododendron* (Rh) cuttings exposed to different mixtures of red and blue light. Lines show polynomial regressions, the R^2 values are shown next the figure legend. Total light intensity was 100 µmol m^{-2} s^{-1}.

As well as affecting cutting survival, light quality also influences rooting. Rooting was improved in grape *Vitis heyneana* subsp. *ficifolia* (syn. *Vitis ficifolia*) when illuminated with red light, compared to or blue light, or to light from fluorescent bulbs (Poudel et al., 2008). When Wu and Lin (2012) propagated *Protea cynarodies* cuttings under red LED light, 67% rooted compared to 7% under conventional fluorescent tubes; while 13% rooted under blue light or a red:blue (1:1) combination.

A second experiment in the LED4CROPS facility examined the influence of far-red light on *Elaeagnus, Photinia*, and *Rhododendron* cutting survival. Far-red light was found to reduce cutting survival (Figure 2) and again this was most pronounced in the *Elaeagnus* cuttings. Currently we have no biological explanation for this response but it is possible that the far-red light is reducing the synthesis of some hormones that are important for root initiation.

However, even without a full explanation of the biology, information from these early-stage trials can be used to improve the light environment in production facilities, either through the use of LED lighting or spectral filter claddings or screens in glasshouses.

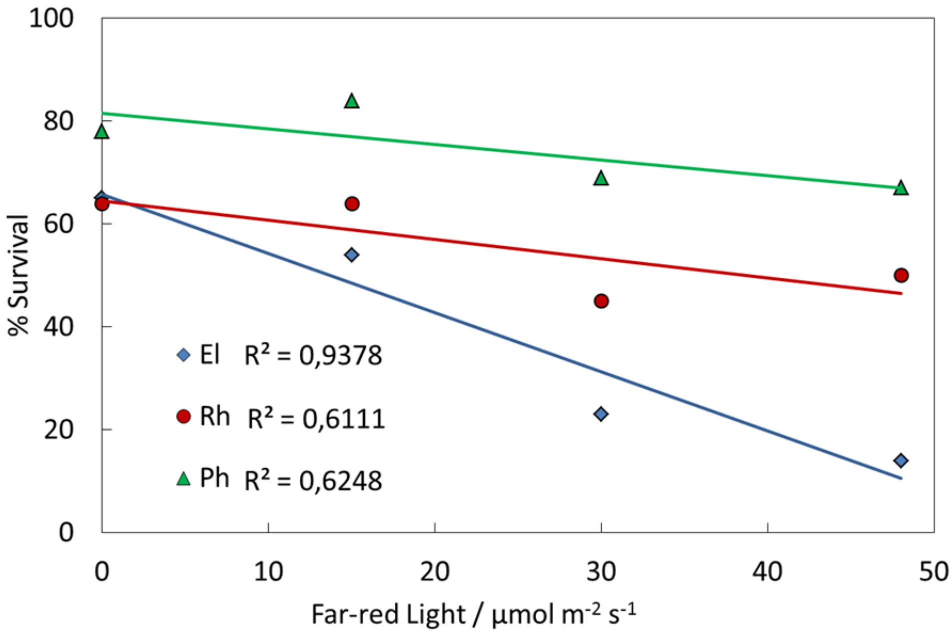


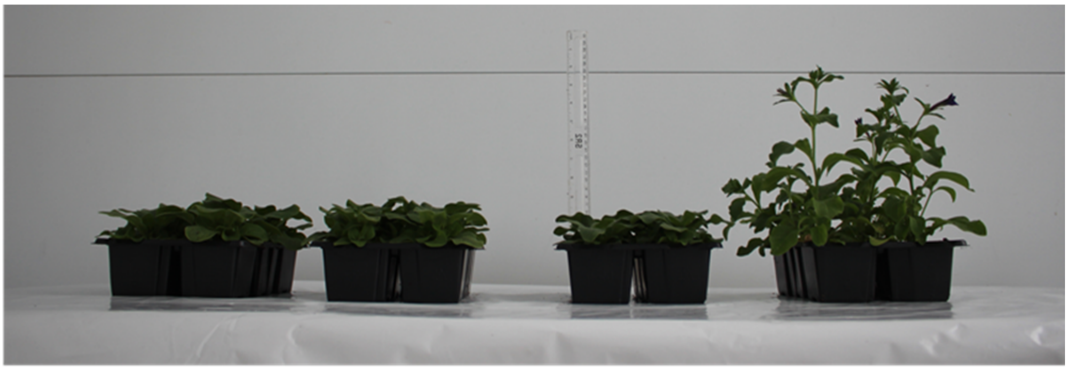
Figure 2. The percentage survival of *Elaeagnus* (El), *Photinia* (Ph), and *Rhododendron* (Rh) cuttings exposed to different amounts of far-red light in a PAR background of 100 µmol m^{-2} s^{-1} (11% blue:89% red). Lines show a linear regressions, the R^2 values are shown next to the figure legend.

LEDS TO CONTROL CROP MORPHOLOGY

Light environments can also be designed to control the morphology of crops during the vegetative stages of growth and to induce flowering. Both red and blue light are required to control plant morphology. In general, for plants grown under red:blue light mixtures with intensities of 200 µmol m^{-2} s^{-1}, compactness increases as the proportion of blue light increases in the mixture from 0 to 60% blue (Figure 3). If the blue percentage is increased beyond this, plants become increasingly etiolated. Careful selection of the light mixture for a crop species or cultivar can enable rapid growth and controlled morphology. The correct light spectrum may control morphology sufficiently to remove the need for chemical plant growth regulators.

While plants can be kept compact their rate of development may also be delayed if the spectrum is not optimised, resulting in delayed flowering. For bedding plants where advanced flowering is required prior to sale, far-red light may be used to induce flowering (Figure 3B). It is, however, necessary to add only just enough far-red light to induce flowering as too much will cause stretching and make it impossible to produce the compact plants required for the market.

A considerable amount of research into the uses of LEDs in different aspects of crop production is currently underway round the world. There are many examples of the use of spectral manipulation for improving propagation efficiency, crop morphology, pigmentation, flavor and aroma. Taken together these benefits have the potential to have a far greater impact on horticulture than the energy saving provided by LEDs.



15% blue 33% blue 66% blue 100% blue

0 FR 15 FR 30 FR 45 FR

Figure 3. The influence of blue light percentage (top image) and far-red light intensity (bottom image) on the morphology and flowering of petunia plants when grown under PAR intensity of 200 µmol m^{-2} s^{-1}.

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