Proposal of LEDs in Vertical Farming Systems

Marta Pozzi and Hayato Nakanishi

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1 LED selection

Three types of LEDs have been selected for our vertical farming project. These LEDs are on the same series made of Cree LED. By combining blue (450 nm), red (660 nm), and far-red (730 nm), the project aims to control the growth of paprika. The selected LEDs have a wide view angle (121-124 deg) and can emit at a moderate PPF (0.72-1.01 $\mu\,\mathrm{mol\,s^{-1}}$). This makes it easy to maintain the desired light mixing ratios across different directions of radiation. The LEDs are also reasonably priced and easily available in large numbers, and it enables to adjust the light emission by changing the number of LEDs. The selected LEDs are shown as below:

1. J Series JE2835 Color LEDs Royal Blue (JE2835ARY-N-0002A0000-N0000001) [ProductLink] [DatasheetLink]
2. J Series JE2835 Color LEDs Photo Red (JE2835AHR-N-0001A0000-N0000001) [ProductLink] [DatasheetLink]
3. J Series JE2835 Color LEDs Far Red (JE2835AFR-N-0001A0000-N0000001) [ProductLink] [DatasheetLink]

Table 1: Selected LEDs basic parameters

Product	Colour	PPF ($\mu\,\mathrm{mol\,s^{-1}}$)	View Angle (deg)
JE2835ARY-N-0002A0000-N0000001	Blue (450-460 nm)	1.01	124
JE2835AHR-N-0001A0000-N0000001	Red (650-670 nm)	0.72	121
JE2835AFR-N-0001A0000-N0000001	Far-Red (720-740 nm)	0.72	121

For the reasons explained in section 2.4 we would like to have 11 blue LEDs, 17 red LEDs and 55 far-red LEDs. In addition they should be turned on 16 hours each day and placed 0.475 m away from the crop surface.

2 Factors in Selection of LEDs

In order to select our LEDs we have considered the spectrum and the intensity of our desired light.

2.1 Spectrum

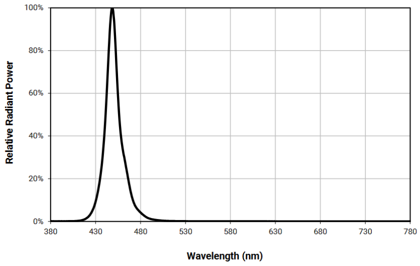
In growing sweet peppers, the combination of red and blue colours has been found to have desirable results in photosynthesis, morphogenesis and growth [1]. This is due to the similarity of red and blue to the photosynthetic properties of chlorophyll, and it is believed that the blue + red combination promotes photosynthesis compared to full-spectrum radiation [2]. In particular blue light steers plant growth, leaf expansion, photomorphogenesis, stomatal opening, photosynthesis, and the accumulation of pigments [3].On the other hand red light plays an important role in controlling the functions of the chloroplast, stem, and petiole growth as well as the reproductive system [4]. Therefore both red and blue light are essential to plant growth. Previous studies have shown that in several red and blue colour combinations, a ratio of red 3, blue 1 promotes the greatest sweet pepper growth [1]. Therefore, our group uses Red (660 nm and Blue (450 nm) as the main light source, replicating this ratio.

Only the first few nanometers of the FR waveband are useful in driving photosynthesis, but if FR light is combined with shorter wavelengths it can improve their photosynthetic efficency [5]. This phenomenon, is known as the "Emerson enhancement effect". Therefore the ratio of red to far-infrared radiation may also influence the growth of paprika. Previous studies have shown that the growth of pepper is predominantly enhanced when the red:far-red (R:FR) ratio is set to 0.3 [6]. R:FR also influences aspects of disease resistance. Plants grown under low far-red light or low R:FR has been shown to have reduced resistance to pathogens and pests. To maintain high R:FR is therefore important for preventing plant diseases [7]. In contrast, the far-red is considered to cause stem growth, which has undesirable effects [1, 2]. However, in this project, the plant has enough space and there is blue light that is thought to inhibit the growth of the stem [1, 2, 7, 8]. In our project, we use more blue light than in these reports cases, therefore the undesirable effect of far red light should be less than the desirable ones and we feel confident in using far red lighting to enhance red bell pepper growth.

We have considered other colours, such as green and UV light, as well, but we have decided not to implement them in our project. Green light is known that has a useful effect on photosynthesis [8]. However, it has also reported low efficacy for photosynthesis with green light [2, 8]. Green light is sometimes used in lighting applications for human vision since it is a suitable colour for human vision.Therefore it can be good to monitore the condition of plants with human vision [2]. However, we thought the green light would not be necessary for this project, as visibility is not a particular consideration.

We also took into account the usage of UV. UV light can be damaging to people and plants, but at low to moderate intensities, they can increase concentrations of certain plants compounds, including ones that influence pigmentation, and avoid plant disease[2, 9, 10]. However, UV has the potential to cause damage to plants ad UV LEDs are are expensive and have short lifetimes. In addition, the effect of the UV is unpredicted due to the few data in the paprika case, therefore we didn't adopt them in our project.

Considering all these factors, we focused on blue (450 nm), red (660 nm), and far-red (730 nm) in our project, as shown in Fig. 1.



Royal Blue

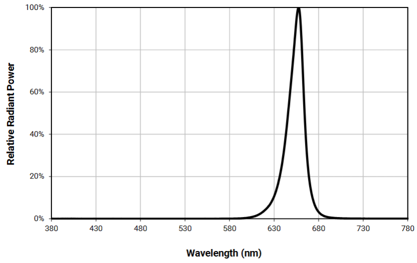
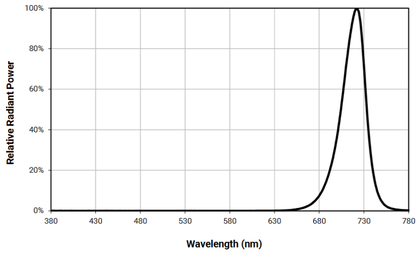


Photo Red

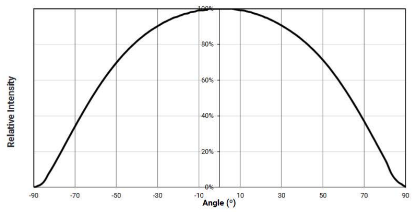


Far-Red

Figure 1: Spectrum of the proposed LEDs

2.2 Uniformed Light

In this project, light has to be uniform with the ratio of red 3 and blue 1 [1]. We took into account this point and selected the LEDs which have large view angle (> 120deg) and compact ones. The irradiance distribution is shown as Fig. 2



Royal Blue

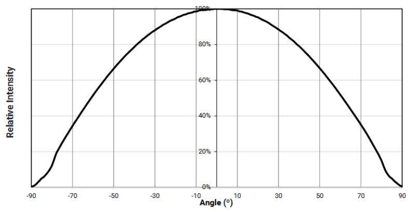
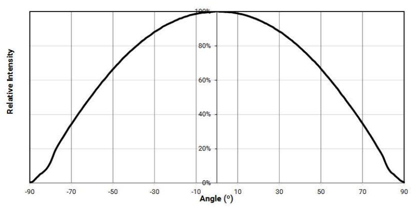


Photo Red



Far-Red

Figure 2: LED Spatial Distribution

Each LED has a large distribution and each distribution pattern is similar to both. We expected it to make light arrangement easy to uniform the light. We have planned to align LEDs as shown in Fig. 3 4.

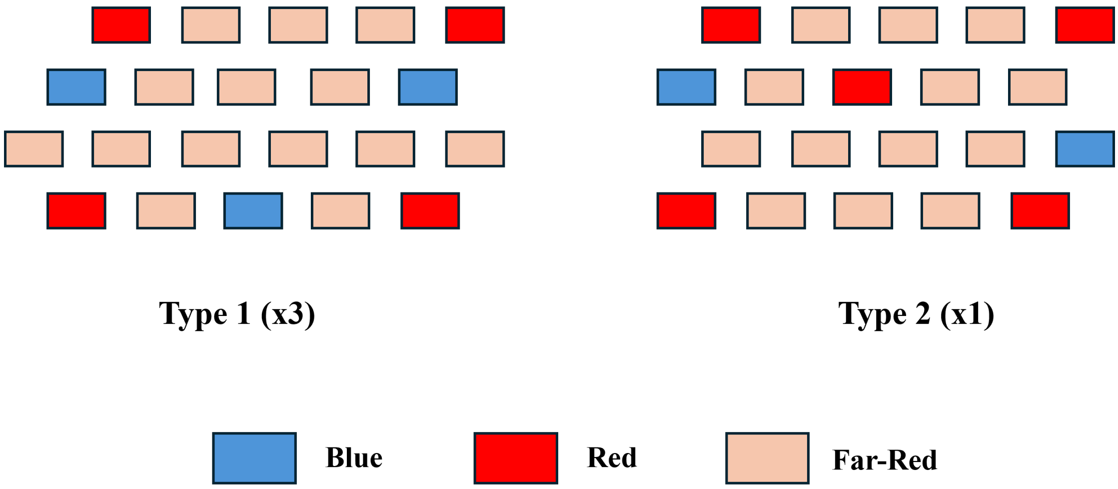


Figure 3: Alignment of LEDs

Two groups of LEDs were designed to maintain a ratio of 3 R:B and 0.3 R:FR. The first group consisted of 3 blue, 4 red and 14 far-red; the second group consisted of 2 blue, 5 red and 13 far-red. Simulation and calculation results show that 11 blue, 17 red and 55 far-red LEDs are used in this project. In order to simplify the design and still meet the requirement for uniform light distribution throughout, a method was chosen in which the LEDs are grouped in units that can maintain the ratio, and the arrangement of each group is determined. The LEDs in each group are arranged as far as possible at the same spacing in order to make the light uniform.

2.3 Arrangement of Light

The avoidance of mutual shading is also an important factor in the growth of paprika [11]. Overhead lighting tends to concentrate light only on the top of the plant, causing mutual shading of the lower part of the canopy and potentially reducing light reaching the lower part of the crop. Also, the irradiance has to be the same for the plant, due to irradiance affecting plant growth and development [12, 13]. The LEDs we selected have large view angle and are compact as already mentioned. These are to expect also uniform irradiance for each plant and avoid mutual shading.

The image of the arrangement of Light is shown in Fig 4.

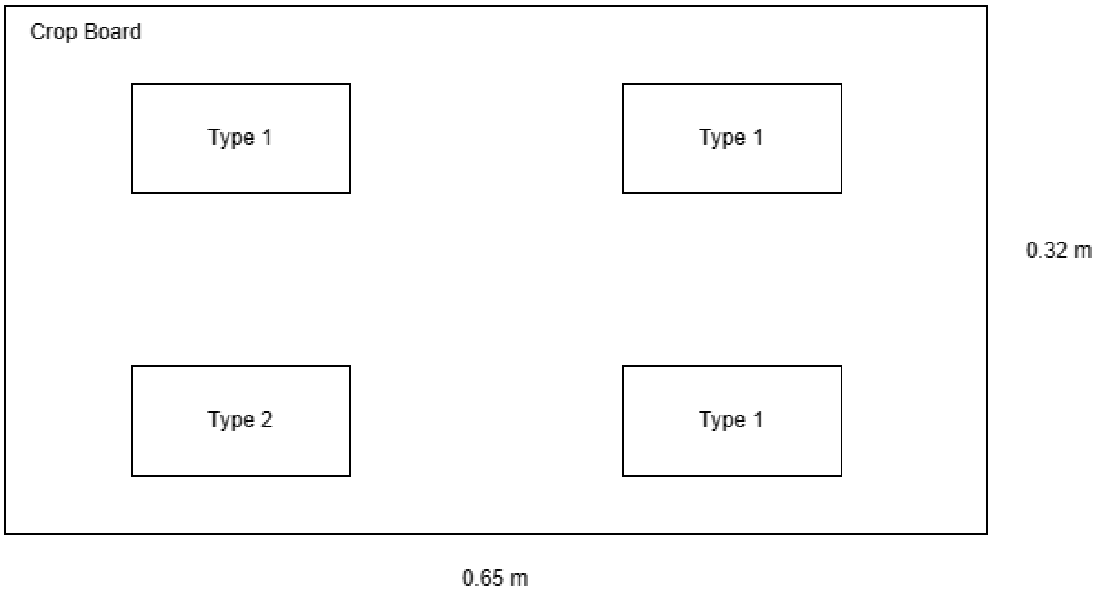


Figure 4: Arrangement of LED groups

To be widely distribution, the light is arranged in 4 positions above the crop board. The LED lamps put on the top of the Plant and the distance between the crop surface and light is 0.475m. It still has potential mutual shading despite the large view angle. Thus, we will cover the shade with a mirror.

2.4 Intesity of Light and number of LEDs

Light intensity is really important because it's the primary factor that influences photosynthesis. To measure the light intensity we consider the photosynthetic photon flux density (PPFD) that is the number of photons within the PAR waveband that strikes a surface of 1 square meter in one second. Therefore the unit is micromoles per square meter and second [$\mu molm^{-2}s^{-1}$]. Research showed [14] that with a PPFD of 200 $\mu molm^{-2}s^{-1}$ and a photo period of 16 hours are the best parameters for red bell pepper growth. The plants area in our project will be 65cmx35cm therefore we need that our LEDs provide in total a PPF of 45.5 $\mu mols^{-1}$.

Considering the PPF of each led, the total PPF wanted, the R:FR and R:B ratio you can find the number of desired LEDs. In our case it's 15 blue LEDs, 10 red LEDs and 33 far-red LEDs. We runned a lightool simulation that showed that to obtain a more uniform light and spectrum it was better to have 13 red, 42 far-red and 8 blue. The simulation also shown that only 60.40% of the emitted light as received on the crop plane. 39.58% of the emission is absorbed by the three walls or the ceiling, therefore we need to emit 63.5119 $\mu mols^{-1}$ in order to have 45.5 $\mu mols^{-1}$ on the crop plane. Considering the found ratio between red, far-red and blue, we found out that we need 17 red LEDs, 55 far red LEDs and 11 blue LEDs.

The simulation also showed that the best position for the LEDs to have is d 0.475 m away from the crop surface in order to have a uniform light distribution.

3 Photoperiod

Photoperiod represents the number of hours of light per 24 hour period. The night length controls the flowering process of crops; indeed crops flower daster when the nights are short. That's why usually in VF crops are grown under 16 to 20 hours photoperiod [15]. However some crops in the solanaceae family, of which red bell pepper belong that develop intumescence (edema) and abnormal growth under 20+ hours of light per day.

Research showed [14] that with a PPFD of 200 $\mu molm^{-2}s^{-1}$the shoot length and plant height are maximal with a photoperiod of 16 hours.

References

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