Horticulture is the branch of agriculture that deals with science, art, technology and business of plant cultivation. Role of light illumination for plant growth is an important factor that needs to be considered and improved. The Photosynthesis process in plants uses water, carbon dioxide intake and incident light as the source of energy to produce glucose, an essential nutrient for the plant, and oxygen as shown in figure 1.

In the past, plant cultivators in green house environments always used either natural sunlight High Pressure Sodium (HPS) or Fluorescent lamps to illuminate the crops which they were growing. There were certain disadvantages in using these light sources because natural sunlight is obviously only available during daytime and fluorescent lighting consumes energy, has a high temperature which prevents it from being placed close to the plant and contains toxic material such as mercury upon disposal.

The development of Light Emitting Diodes (LED) in the last few decades has introduced a new source of lighting to horticulture with many superior advantages. First of all the plant does need all wavelengths in the visible region (400-700 nm) in equal proportion. Photosynthetic Photon Flux (PPF) designates the range of visible spectral radiation which plants use in photosynthesis process. Plants use more of Red and blue light for photosynthesis than green as shown in Figure 2.
The absorption spectrum of plants can be matched by using tunable LED’s as shown in Figure 3 below. This illumination source is much more suitable than an HSP source whose peak emissions widely differ from the absorption spectrum of green plants.

![Absorption spectrum of green plants](image)

**Figure 3: Absorption spectrum of green plants**

This illumination source is much more suitable than an HSP source whose peak emissions widely differ from the absorption spectrum of green plants as shown in Figure 4.

![Rate of Photosynthesis and HPS intensity vs. Wavelength](image)

**Figure 4: Rate of Photosynthesis and HPS intensity vs. Wavelength**

Some wavelengths of interests for LED’s as applicable to plants growth are:

- 200-280nm or UVC radiation is present in sunlight but harmful to plants.
- 320-340nm may have a small effect on cryptochrome.
- 365nm is a “wavelength of interest”
- 439nm the blue absorption peak of chlorophyll A
- 450-460nm royal blue is absorbed by one of the peaks in beta-carotene It is a readily available LED wavelength, commonly used to excite the remote-phosphor in “white” LED lamps
- 469nm is the blue absorption peak of chlorophyll B
- 430-470nm range is important for the absorption of chlorophyll A and B. This is key for vegetative growth
• 480-485 nm is the second absorption peak of beta-carotene
• 525 nm is a phototropic activator our researchers are still trying to find the chromophore of. It is apparent that plants are gaining direction and environmental signals from it and it affects internodal distancing. 525 nm is also the wavelength of GaN or InGaN green LEDs commonly used in RGB and tunable applications.
• 590 nm is key for carotenoid absorption. Carotenoids are both starch storing, structural compounds and nutritional compounds. With thanks to Jeffery Bucove who increased the harvest bulk of his plants by adding this wavelength.
• 590 nm in addition is the phycoerythrin single absorption wavelength.
• 625 nm is the phycocyanin single absorption peak.
• 642-645 nm is the peak absorption point of chlorophyll B
• 660 nm often called the super-red LED wavelength is important for flowering
• 666-667 nm is actually the peak red absorption point for chlorophyll A.
• 700 nm light is to be avoided. It confuses the phytochrome recycling systems in green plants.
• 730 nm, often referred to as Far Red is important for phytochrome recycling. It is needed for all kinds of morphogenic processes. A few minutes of 730 nm light treatment after the full light cycle is over will revert the Pfr (activated) to the Pr (inactive) form of the phytochrome chromophore. This resets the chemistry for another “lights-on” cycle, and may be useful in shortening the classic dark side of the photo-period. 735nm is the closest available standard LED wavelength to the above 730 nm.

LEDs provide the unique opportunity for horticulture industry to use a narrow bandwidth of illumination. Several LEDs at different wavelengths can be combined to provide an illumination source which follow the plant sensitivity curve. Aside from this, there are several other advantages of using LED’s in horticulture which include:
• Geometry: Since radiation falling on a plant is inversely proportional to square of distance between the source of radiation and plant, it is advantageous to bring the plant close to the light source. This is possible for LED sources because they are cooler in temperature whereas for fluorescent lamps the produced heat will burn the leaf at close distances.
• Efficiency: Electrical efficiency of LEDs are much higher than Fluorescent lamps which helps the crop grower to save in electrical bills.
• Durability: By definition the lifetime of LED is defined as the duration at which the intensity drops to 70% of its original value and this is about 50,000 hours, much higher than a typical life time for a Fluorescent lamp.
• Spectral quality: Spectral quality of carefully chosen LED illumination source, can have dramatic effects on plant anatomy, morphology and pathogen development.
• Small size: Allows bigger space for installing the light source

Figure 5 shows LED illumination is a greenhouse.

The wavelength selection of illumination is observed in the figure. Several researches have experimented with effects of different intensity and wavelengths on growth of different crops. It is important to understand that different crops may behave differently under different illumination levels and a different “light recipe” may be needed for each crop. The PPF is measured in units of mmol/m²/s (One mole is 6.023 x 10²³ photons) and crop
growers have experimented with different levels of light intensity. Increased PPF has caused in increased growth of the plant. Although red light is sufficient for plant growth, blue light is important for increased leaf thickness and number of chloroplasts/cell. Rice plants grown a combination of blue and red LED’s showed a higher photosynthetic rates than those grown under red illumination alone (Reference 1). Although a combination of Red and Blue LED illumination is very useful for better crop growth, since it appears to be purplish grey, it makes it difficult to observe the disease in plants visually. Addition of green light, although not important for plant growth makes it possible to assess the damage by human eye.

Another important issue is development of metrics for quantifying PPF and light absorption by crops. Crop growers need to calibrate their LED light sources and find the optimum light recipe as far as flux efficacy, appropriate wavelengths for different crops and optimum geometry of illumination is concerned. CDE Technology BV has recently introduced the SGAL App which allows the photometric measurements of LED light sources applicable to horticulture. The PPF measurement is simply done by pointing the device at the light source and pressing a button. The software also has features which allows recording of data on a day to day basis and monitoring the growth of the plant. These diaries will help the grower to closely monitor the best course of action. Figure 6 shows highlights of this new interesting device.