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Effect of light parameters on plant growth–A Review

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ABSTRACT

The plant growth is mainly dependent on few environmental factors like light, humidity, temperature, water,carbon-di-oxide. The light affects the production, appearance, metabolism, morphology, circadian cycles and nutrition of the plant. Light source selection and control is an indispensable aspect that affects the plant system. A review of comparison of various light sources have been made. Also the effect of light spectrum, light intensity and photoperiod have been discussed for various plants. The cause, effect, measurement and control of the junction temperature of LED light source has been discussed.

Keywords: Controlled environment, junction temperature of LED, Light intensity, Light spectrum

1. INTRODUCTION

The rise in the temperature, global climate change, food supply demand and environmental pollution that the earth experiences due to increase in certain gases mainly carbon di oxide and increase in population there is a demand to grow plants.Growth of plant is an issue mainly in the region with harsh weather conditions. The green house has the potential to maintain the environmental conditions that promotes the growth of plant and therefore has the potential to meet the need for increased food demand, carbon-di-oxide control etc. Hence, it can be considered as a measure to protect environment, to save resources and retain food safety. There are many environmental parameters that play an important role in the growth of plant like humidity, temperature, light, water, carbon-di-oxide etc[1].

Among the various environmental factors light selection and control is an important factor. Light is a primary source of energy for plants. Plants cannot directly process light hence is converted by plants to produce glucose and the process is referred to as photosynthesis. Light also provides information about the status of the above ground environment. Light intensity, light spectrum and photoperiod are the important light parameters that effect the plant.. The light intensity, light spectrum and duration that the plants receive has an effect on flowering, photosynthesis, plant shape, climate response, stomatal conductance, orientation, internode length and production parameters[2].

Light is perceived by plant photoreceptors like chlorophylls, carotenoids, phytochrome, cryptochrome, phototropinand hence generating a wide range of physiological responses [2].Absorption spectra of few photoreceptors are shown in Fig 1.1 [2]. Chlorophylls mainly absorb the red and blue spectrum. Carotenoids are blue light receptors that not only contribute in photosynthesis but also protect plants against over-exposed light. Phytochromes have two interconvertable forms Pr and Pfr which also mediates the photomorphogenetic responses like stem elongation, flowering, germination, leaf expansion [1][2].

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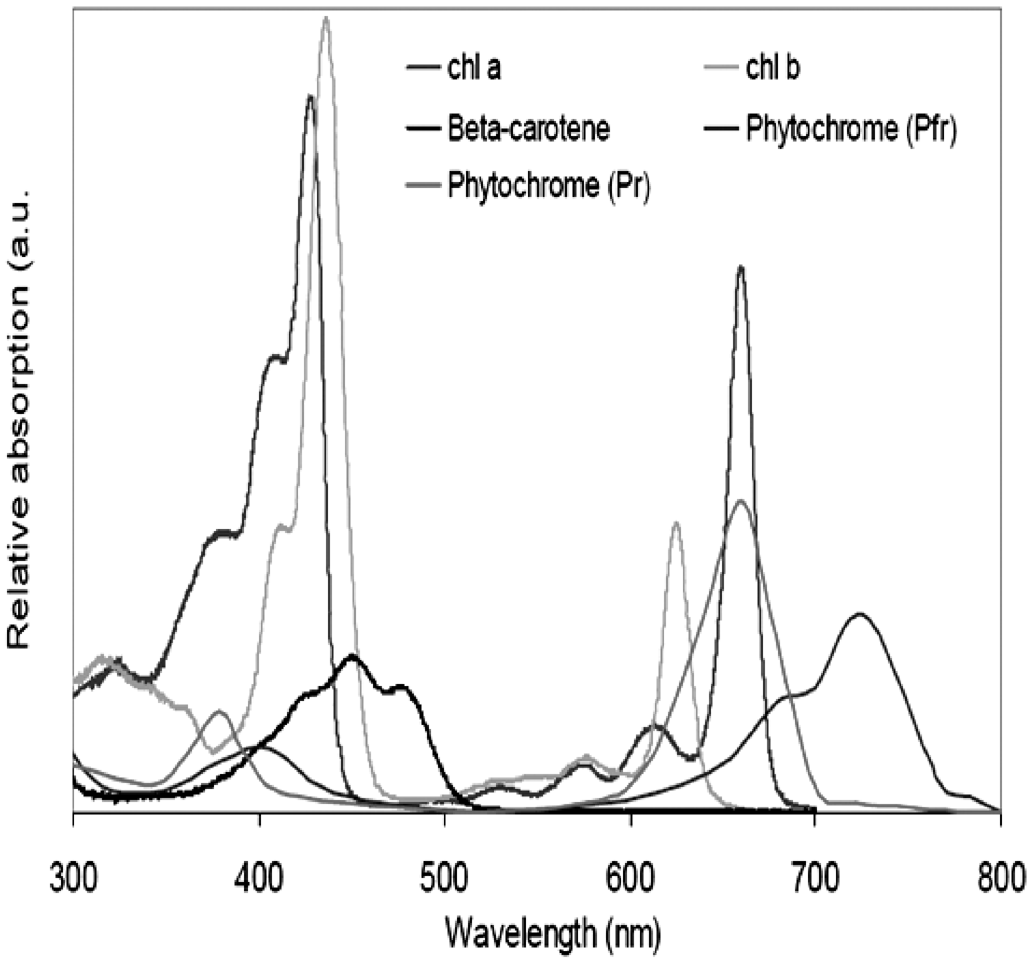

Figure 1: Absorption spectra of the receptors in green plants [2]

Cryptochromes are blue light receptors that controls circadian rhythms, de-etiolation, stem elongation, leaf expansion and flowering time [3].

In addition to the light parameters the mounting height also plays an important role in the productivity of crops.The efficient use of energy is dependent on the heat produced and mounting height of the lamp (dependent on plant shape, size and height) [3]. The LED lamps are cooler hence can be placed closer to plants [4].

Light in the visible region (320nm-720nm) is mainly used by almost many plants. The wavelengths below 300 nm i.e UV spectra have high energy. This high energy can break the bonds in the molecules, and hence can destroy DNA structure and other important structures. The wavelengths above 800 nm i.e IR spectra has less energy and therefore does not excite the electrons in the molecules hence, not enough to be used for photosynthesis. They are generally converted to thermal energy.

2. LIGHT REQUIREMENT FOR PLANT GROWTH

The major light parameters that promotes plant growth are:

2.1. Light intensity

2.1.1. High intensity radiation

Under high intensity radiation the unused radiation tends to generate potentially damaging heat on the surface which is dissipated mainly through evaporation. Evaporation not only cools the leaf surface but also promotes the entry of dissolved nutrients. As a rule, greater the intensity greater the rate of evaporation. Hence, after this point of high level condition when the evaporation must still increase more than it extracts it partially closes the stoma to conserve water and prevent wilting. This effectively slows down photosynthesis. After this point when the intensity still increases it stops photosynthetic output and permanently damages the plant tissues [4].

2.1.2. Low intensity radiation

The plant senses or measures the length of the night/ day using phytochrome. Since plants are very sensitive even for some relatively low intensity and many plant species time their growth in concert with the seasons like flowering the low intensity effects photoperiod, photomorphogenesis and phototropism [4]. However, in few solanaceous and leguminous species the use of LEDs create abnormal intumescence on leaves and shoot tips and it doesn't occur for broad band light source because of the inclusion of UV rays [3].

2.2. Light spectrum

In the rice plants, grown under red supplemented by blue (4:1) LED light at 1600µmol/m^2/s and 250µmol/m^2/s had enhanced both light saturated and light-limited photosynthesis than the plants grown under red LED light alone [5].

Lettuce plants grown under red light alone had more number of leaves and longer stems compared to plants grown only under blue [3]. A tradeoff between blue and yellow light along with red light can further enhance plant morphogenesis. The growth results depended on whether the LEDs were used in the presence or in the absence of daylight [6].

Wheat plant could complete the life cycle with red light but addition of 10% blue light increased culm leaf, flag leaf and number of tillers. However, the shoot dry matter and photosynthetic rates increased with increase in blue light [3]. Yield and dry matter weight of spinach, lettuce and radish increased with the addition of blue light. In cowpea plants when the blue light was reduced below 10% to 15% of total radiation the older leaves had abnormal edema. Shoot length of potato plantlets increased when the PPF was increased [3].

RGB light grown lettuce plants had higher fresh and dry weight, greater leaf area compared to RB and cool-white fluorescent lamp light grown plants. However, it has no significant effect on the growth pattern. However, more than 50% green light reduces plant growth and combination up to 24% green enhances growth in some species [3].

In the *Potentilla* species, the changes in light quantity primarily affect growth and production parameters (dry weight, leaf number, leaf area, ramet number), while alteration in the spectral composition of light mainly influences developmental processes and plant morphogenesis. Morphological and architectural traits were generally most sensitive to alterations in the spectral light quality [7].

Hence we can say that the plants are sensitive to light spectrum [6]. The red, blue and green light plays an important role in the plant growth and are being discussed below:

2.2.1. Blue light

The growth of plant, absorption of nutrients, and growth of sturdy stems are all affected by blue light [3]. It also plays an important role in the plant morphology like phototropism, stomatal control, stem elongation and also effects the water relations and carbon-di-oxide exchange [3]. Stem growth is excessive if the blue light is insufficient and leaves turn yellow [9]. The amount of blue light required for different species is different [6].

2.2.2. Red Light

Red light is mainly used in photosynthesis because they are efficiently absorbed by plant pigments. Red and Far-red light are used by plants to sense day and night [4]. Flowering phase, relies more heavily on light in the red range of the spectrum [3].Interchange between the presence and absence of red light cause stems and leaves of plants to grow [9]. Ratio of red and far-red has a great impact on seedlings [3].

2.2.3. Green Light

Plants grown under RB light appears purplish gray. Hence it is difficult to diagnose disease and disorder. The solution to this problem is addition of green light because human eyes are more sensitive in this spectrum. It effects the colouring of leaves [3].

2.3. Photoperiod

The roses were subjected to two different photoperiod treatments 1) 16hr : 8hr 2) 19hr :5hr with 16:4 red: blue LEDs and fluorescent lamp at 70 μmol/m^2/s. The results indicated that the number of leaf, plant height and number of shoots increased with longer photoperiod regardless of the plant growth regulators kinetin and benzylaminapourine used. [10]

Miniature roses were treated for 3 different photoperiod with and without dark period at two intensity levels 100μmol/m^2/s and 150μmol/m^2/s. The result concluded that the time of flowering and powdery mildew decreased, number of flowers, dry weight, mean growth rate until flowering, plant heightincreased, water loss was high for plants grown without dark period with the increase in intensity and 20hr/day with dark period at 150μmol/m^2/s was the best suited for plant growth [11].Hence, the photoperiod and light intensity are interdependent.

3. SUPPLEMENTARY LIGHT SOURCE

Under harsh environmental conditions there is a need for supplementary lighting which is provided by artificial light sources.Various light sources available like the incandescent, fluorescent, HPS and LED's are compared in terms of their optical and electrical parameters [1]. The incandescent lamps, fluorescent lamps and the HPS are termed as conventional lamps and are compared against LED's.

3.1. Converntional lamps

Incandescent lampsdonotrequire ballast but have low electrical efficiency, low light emission in the photosynthetically active region (PAR), fixed and unbalanced spectrum. They produce lot of heat hence there is a need for ventilation which in turn increases the cost.Also has a short life span. The spectrum is strong in red/far red region hence used to control photomorphogenetic responses through mediation of phytochromes. Also floral initiation can be achieved with long day responsive species [1][2][4][6]. Fluorescent lampshave higher electrical efficiency, more light emission in PAR region compared to Incandescent lamps. Theyalso produce less heat hence longer life. They can be placed close to plants. The spectrum produces balanced morphology for most crops [1][2][4][6].High Pressure Sodium (HPS) lampshave higher electrical efficiency, more light emission in PAR region compared to Fluorescent lamps. They produce heat however has longer life. Due to low red/far-red ratio and low blue light emission in comparison with other sources they are not optimal for promoting photosynthesis and plant morphology [1][2][4][6].

The incandescent lamps, fluorescent lamps and HPS lamps suffer from restricted controllability, long ignition times, and dimming range limitations. They may require additional filters for obtain desired spectra [1][2][4][6].

3.2. LED's

LEDs work on the principle of electroluminescence. LEDs are energy efficient, versatile and appropriate to control the light intensity, light spectrum and periodicity. The LEDs can be chosen such that their wavelengths match the absorbance peaks of important plant pigments without the use of additional filters. The adjustment of light intensity at various growth stages not only decreases the energy consumption but also shortens cultivation cycle and improves quality. They are safe to handle and dispose [1][2][4][6].

4. ISSUES IN THE STABILITY OF LIGHT PARAMETER

LEDs considered the best choice for growth of most of the plants. However, it is difficult to maintain a stable the wavelength and the intensity required for growth of plant. The problem arises because of the increase in junction temperature of LED [1][2][4][6]. The junction temperature increment is caused due to power dissipation, large forward current and device ageing. It effects the LEDs forward voltage, photometric characteristics, peak wavelength, color point, color temperature, spectral width and life time [12].

The variation of the drive current and junction temperature effects the peak wavelength and therefore the correlated color temperature (CCT). When the current is small and the junction temperature is less the peak wavelength shift towards blue spectrum and when the current is large, the junction temperature increases. After a certain point where the junction temperature effect is dominating than the current effect the wavelength shift towards red region. Hence the selection of current levels, duty cycle, thermal resistances of the heat sink and device, heat dissipation conversion ratio and the physical parameters of the LED device are important [13].

Direct measurement of junction temperature is difficult because of small area. So the heat sink temperature on which the LEDs are placed is measured using temperature sensor, thermocouples, infrared cameras, forward voltage method etc which includes thermal resistance. Hence they require control loops to be included. In the feed forward compensation the effect of junction temperature on wavelength and flux is used in the lookup table and fed to the compensator. However the interdependency of flux and wavelength is not precisely known and the change in LED flux due to ageing is not considered. In the feedback control, the flux is sensed using photodiodes and the values are sent to the controller and compared against reference and the corrective action of varying the current is performed. For RGB LEDs, three photodiodes with three feedback loops is required. The flux variation due to ageing and junction temperature is considered but the wavelength variation due to junction temperature is not considered. Hence a combination of feed forward and feedback loop is introduced which gives the advantages of both the above scheme. However, in the above mentioned three schemes a precise relation of variation of flux, and wavelength with junction temperature must be known. Hence another scheme where the color coordinates are considered is discussed. Apart from using normal light sensors we can use special light sensors whose spectral responses match the CIE 1931 color matching functions that directly give us the color coordinates. This sensor consists of photodiodes and optical filter. However, when considered for a lamp to know the color coordinates as a function of junction temperature is time consuming and expensive. High reproducibility of color control is difficult with this compensation scheme. A high degree of color accuracy is possible with this scheme [14].

5. CONCLUSION

A brief discussion on the plant growth parameters of various species with respect to light intensity, light spectrum, photoperiod and mounting height is made.Exposure of plants to low intensity with longer photoperiod is better than exposure of plants to high intensity with shorter photoperiod. The review also presents that the combination of red and blue light alone may not provide the ultimate solution for the optimal growth of some specific plants. However, the plants are sensitive to minor changes in spectral composition of the radiation. Various light sources are compared and discussion on the junction temperature of the LED is made

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