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Lighting on Agriculture and Using Light Emitting Diodes

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ABSTRACT

In agriculture, light is one of the most important factors affecting productivity. Artificial light sources used to support the energy coming from the sun support the formation of photobiological events. Light sources used in artificial lighting should be suitable for the requirements of plants, safe, environmental and have low energy requirements. LED-type light sources are artificial lighting tools that have become more common in recent years. In this study, the place of light in agriculture, classical lighting and technological features of LED type light sources are investigated. The advantages and operation of LED are emphasized. In addition, effects on plant were tried to be explained.

Keywords*—Light, PAR, Diode, photosynthesis, photon*

I. Introduction

According to the researches, the world population will be 9.1 billion in 2050. Today, while 49% of the world's population lives in urban areas, this ratio is expected to be more than 70% in 2050 [1]. If traditional farming methods continue to be implemented, new agricultural areas larger than the Brazilian area will be needed to feed this population. 80% of the area suitable for agriculture on a world scale is already cultivated. However, statistics show that 15% are unusable due to poor management. [2].People's learning to mow the land allowed them to move to settled life and to build advanced civilizations. It was a revolutionary change. In the following years, different methods have been developed in order to increase agricultural productivity to meet the nutritional needs of people. By using various chemicals (known as pesticides), insects, weeds and fungi that damage agricultural products can now be neutralized. In addition, many agricultural products can be grown in almost all seasons in the greenhouses where the factors affecting growth such as temperature, humidity and light are controlled. However, these methods will not be enough to meet the food needs in the future due to the increasing world population.

Agricultural practices in which agricultural products are produced in facilities where environmental conditions are controlled are called artificial agriculture, vertical agriculture or landless agriculture. In artificial agriculture, plants are not cultivated in large areas such as in traditional agricultural practices. Instead, it is necessary to establish plants where the conditions necessary for the growth of plants (eg temperature, light, water, carbon dioxide, nutrients) are always kept at optimal value. In this way, it is planned that agricultural products can be grown at the desired place, at the desired season and at the desired time regardless of the external factors such as season and weather conditions.

The basic bond of humans and animals with life is established through plants that perform photosynthesis using light energy. Therefore light; It has always played a very important role in the lives of all creatures. Artificial lighting has come to the fore when the sun is the biggest light source, also when the rays are less, technologies have been developed for this purpose. LED type illumination tools are also a product of technology oriented studies.

II. Conventional Lighting In Agriculture

In agriculture, broad spectrum light sources such as high pressure sodium (HPS) or fluorescent lamps are used as conventional lighting systems, especially for greenhouses. These lamps are excellent light sources for the human eye, but are not the most efficient light sources for plant production due to low blue light levels and other photosynthesis sensitive wavelengths. Light emitting diodes (LEDs), which can produce specific wavelengths by creating a specific light spectrum targeted for maximum plant production, can be said to be a fifty-year technology demonstrating potential in the greenhouse industry. Scientific studies have shown that the most important wavelengths for photosynthesis are in blue and red wavelengths; The peaks in photosynthetic yield are found at 440 (blue), 620 (red) and 670 (red) nm (+/- 10 nm) [3].

Light is an electromagnetic wave energy with particle (photon, quantum) character. Electromagnetic waves that generate light from a source propagate with sinusoidal motion and at constant speed. The rate of propagation to the frequency of sinusoidal motion; wavelength. In the classification made according to wavelength, 380-780 nm range; because it can be perceived by the human eye, it is described as a visible light zone [4].

Plants, chlorophyll formation, photosynthesis, conversion of inorganic substances to organic substances, shoots, leaves, flowers and fruit needs light for the formation [5].The source of light needed for plant development is the sun or artificial light [6,7].The light coming from the sun to the earth is composed of different wavelength rays. The wavelengths of the light in the spectrum between 390 nm and 760 nm are called visible light[5]..In the visible light spectrum, the red-orange light wavelength (600-700nm) is the longest light [8].Plants use visible light in the spectrum when performing photosynthesis [5].The energy of photons with visible wavelengths from the electromagnetic rays emitted by the sun is used by the plants in photosynthesis [9]. Light is not only an energy source for photosynthesis but also a factor that controls and directs different developmental processes for plants [10,11].Many light-related factors, such as light intensity, wavelength, are effective on plant growth parameters (such as node length differences, plant height, branching pattern, leaf sizes and biomass) [12,13,14,15,16,17].The amount of light affects the photosynthesis process. This process is a photochemical reaction within the chloroplasts of the plant cells in which CO_2 is converted into carbohydrate under the influence of the light energy. The spectral composition of red, far red blue, green, yellow or invisible e.g. UV or IR of the different wavelength regions is important for the grows, shape, development and flowering (photomorphogenesis) of the plant. For the photosynthesis, the blue and red regions are most important [3].

The timing / light duration is mainly affecting the flowering of the plants. This is called photoperiod. The flowering time can be influenced by controlling the photoperiod (Fig. 1).

Photosynthetic efficiency is mainly driven by chlorophyll a and b. They are mainly responsible for the photosynthesis and responsible for the definition of the area for the photosynthetically active radiation PAR. It shows further photosynthetic pigments also known as antenna pigments like carotenoids (carotene, zeaxanthin, lycopene and lutein etc.)in Fig.2 [18].

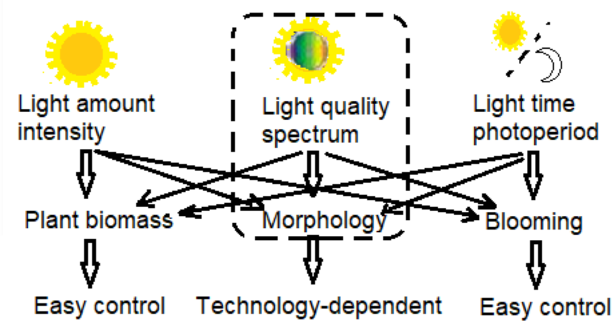

Figure 1. Effect of light on plant [52].

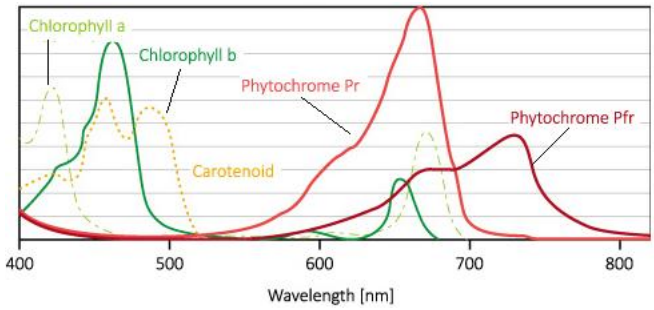

Figure 2.Absorption curves of plants [18].

If we examine traditional plant lighting sources;Incandescent lamps emit light upon the heating up of a metal filament. The fluorescent lamps, high-pressure mercury, high-pressure sodium, and metal-halide lamps are gas discharge lamps since they emit light generated by an electrical discharge through an ionized gas. While gas discharge lamps emit photons by the release of energy from thermionically excited electrons, emission from incandescent lamps consists of thermal radiations. The fluorescent lambs are low-pressure lamps in gas discharge lamps. But high-pressure sodium lamps, the high-pressure mercury lamps, and metal-halide lamps are termed as high-intensity discharge lamps due to the high pressure of gases in the arc tube.

Incandescent lamps, the working principle behind Incandescent lamps, is the phenomenon by which a solid starts emanating electromagnetic radiations in the visible range upon being heated [19]. Their oldest designed lamp consisted of a platinum coil enclosed in an evacuated glass tube, by Rue in 1840.

An incandescent bulb typically consists of a glass enclosure containing a tungsten filament. An electric current passes through the filament, heating it to a temperature that produces light. Incandescent light bulbs usually contain a stem or glass mount attached to the bulb's base which allows the electrical contacts to run through the envelope without gas/air leaks. Small wires embedded in the stem support the filament and/or its lead wires. The enclosing glass enclosure contains either a vacuum or an inert gas to preserve and protect the filament from evaporating. In other words, the bulb is essentially made devoid of oxygen by evacuation or by filling up with an inert gas to prevent the burning up of the filament. The filament is made of a metal It has high melting point and low coefficient of thermal expansion. Tungsten has both of these properties. It has been the only metal used for producing the filament for Incandescent lamps, recently. The two lead-in wires connected to either ends of the filament are connected to the external circuit. The lamp operates when the electrical current flows in from one lead wire, through the filament and out of the second lead wire. Because of the filament has higher resistivity than the lead-in wires, it impedes the flow of electrons. The inelastic collisions between the moving electrons and the electrons within the filament lead to the conversion of the kinetic energy of the moving electrons into atomic vibrational energy. This causes the filament to gradually heat up (2800 K). It then begins to dissipate energy as electromagnetic radiation. It emits radiations in the entire visible range. The intensity of the radiations increases from 400 to 700 nm. A significant portion of the energy is also dissipated as far-red emission which can reach up to 60% of the total PAR (Photosynthetically Active Radiation)[18].

They provide warmth to plants and not produce broad-spectrum emissions. So they are used in indoor cultivation in winter. But because of the low luminous output in exchange of the high electricity input, the operations were not deemed economically feasible. Heat losses and poor electrical efficiency are more important the gain in plant growth and yield. The energy conversion efficiency for the various modern Incandescent lamps ranged between 1 and 5%, with the luminous efficacy never exceeding 20 lumens/watt. Availability of power-efficient and long-lasting gas discharge lamps gradually replaced the Incandescent lamps as a light source for indoor cultivation[18].

The carbon arc lamp is a lamp that produces light by anlectric arc. The carbon arc light, which consists of an arc between carbon electrodes in air, invented by Humphry Davy in the first decade of the 1809s, was the first practical electric light. The application of this lamp was limited owing to the characteristic color of light it gave off. In 1936 Philips launched the first high-pressure mercury vapor lamps. General Electric became the first to commercially produce fluorescent lamps in 1938. In 1962, metal-halide lamps were developed. Two years later high-pressure sodium lamps emitting bright white light developed were launched commercially[18].

Low-pressure mercury vapor discharge lamps, fluorescent lamps, produce visible light due to the fluorescence of a phosphor coating. They have two type on the basis of their shape and size—tubular and compact. The luminous efficacies of the two designs differ significantly. But their working principle is essentially the same. Both of them consist of an airtight hollow glass tube filled with a mixture of mercury and argon vapors in a low-pressure environment. The inert gas present in the arc tube promotes the ionization of the gaseous metal (mercury) atoms. The two ends of the tube have electrodes composed of tungsten filaments projecting into the vapor mixture. Upon the passage of electricity, the filament gets heated up and starts emitting electrons [20].Since fluorescent lambs work on alternating current, the two electrodes alternately emit electrons every half cycle. The electrons get accelerated toward the opposite electrode through the mercury vapor mixture due to the applied voltage. The electrons collide with the valence electrons of the mercury atoms causing electron impact ionization which leads to the release of more free electrons into the vapor mixture. At this stage, the vapor starts conducting electricity freely. The mobile electrons cause the excitation of the other electrons in the outer orbitals of the mercury atoms. The excited electrons fall back to the ground state and in the process emit radiations in the UVrange. These high-energy UV photons are absorbed by the phosphor coating which fluoresces or starts emitting photons of lower energy. Since the emission spectrum of an fluorescent lamb entirely depends upon the phosphor coating, a wide variety of phosphors have been used for developing white and colored fluorescent lambs.

Energy losses in anfluorescent lamb occur in the ballast which supplies a pulse of high voltage to initiate the discharge. However, a significantly higher amount of energy is lost during the conversion of UV rays into visible light where almost half the energy of each photon is lost as heat. However, the overall energy conversion efficiency of the fluorescent lambs is still below 30% [21]. Because of the white light output that appositely mimics daylight, fluorescent lambs have been a popular source of plant lighting in small- and large-scale operations. Approximately 90% of the photons emitted are in the PAR region. Spectral output of fluorescent lambs cannot be regulated and the surface of the lamp becomes considerably hot during operation.

High-intensity discharge light bulbs and lamps, are a family of gas-discharge arc lamps which create light by sending an electrical discharge between two electrodes and through a plasma, or ionized gas. An additional gas is generally used, and this gas serves as an easy way to classify the major types of High-intensity discharge light lamps: Mercury, sodium, and metal halide. These lamps are known for their high efficiency at turning electricity into light and their long rated life. The Lamps require a ballast in order to generate the initial surge of electricity needed to start them and to regulate their power during normal operation. The basic technology for the gas-discharge lamp has existed for over 300 years, and these same principals also guided innovations in other lighting types such as fluorescent and neon. The invention of the gas-discharge lamp is generally credited to Francis Hauksbee, an English scientist, who first demonstrated the technology in 1705.

At the time, the lamp was filled with air, but it was later discovered that the light output could be increased by filling the lamp with noble gases, such as neon, xenon, argon, or krypton. This technology has further increased light output through experimentation in gas mixtures and improved electrodes, but the functional basics of the high-intensity discharge lamp remain the same. In modern lighting usage, the High-intensity discharge light lamp functions by sending an electric arc between two tungsten electrodes which are housed in an arc tube, usually constructed of quartz. The tube is filled with an amalgam of gas and metal salts. An arc is created with an initial surge of electricity, facilitated by the gas in the lamp. The arc then heats the metal salts, and a plasma is created.This increases considerably the light produced by the arc, resulting in a source of light which is more efficient at creating visible light instead of heat than many traditional technologies such as incandescent or halogen lamps.

The high-pressure mercury lamps contain a mixture of mercury and argon vapors like fluorescent lambs, but the pressure is more higher in an fluorescent lamb. The vapors are maintained in a quartz arc tube which housed inside an outer envelope made of borosilicate glass filled with nitrogen, to withstand the high pressure and operating temperature. By the emission of electrons from the tungsten electrodes the ionization of mercury atoms is triggered. The frequency of electron impacts on the mercury atoms becomes very high due to the high pressure. The generation of a huge amount of heat occur. In other words, the mercury electrons get ionized to higher excitation states, leading to the emission of radiations at certain wavelengths in the visible range along with the UV radiations. A phosphor coating provided on the outer envelope converts the UV radiations into different visible wavelengths. It results in white light [19].

The high-pressure sodium lamps have greater coverage over the visible spectrum than the mercury vapor lamps. Because there are the presence of sodium vapors along with mercury in the arc tube. Further, the tube is pressurized with xenon. The vapors are maintained within a ceramic or polycrystalline alumina tube which can withstand the corrosive nature of sodium vapors at high temperature and pressure [19].The excitation of mercury and sodium atoms occurs by the bombardment of electrons from the tungsten electrodes. The electron impact ionization coupled with thermal ionization results in electrons jumping to various higher energy states, while falling back to the ground state, the electrons emit electromagnetic radiations covering a wide range in the visible spectrum.

Higher luminous efficacy (80–125 lm/W) and broad emission spectrum of high-pressure sodium lamps have made them a popular source of electrical lighting in public spaces and industrial buildings. A high emission peak in the 560–610 nm range renders a distinct yellow coloration to the light produced which limits its applications. Further, the unbalanced spectral quality in relation to the absorption peaks of chlorophyll a, b and b-carotene makes them unsuitable for promoting photosynthesis and photomorphogenesis. Compared to other conventional sources, high-pressure sodium lamps with high electrical efficiencies of 30–40% are the most energy-efficient light sources used in plant growth [18].

In the metal-halide lamp the inclusion of metal halides along with the mercury vapor and inert gas permits the optimization of the spectral quality of the emitted radiation to a certain extent. Metals such as sodium, scandium, indium, thallium, and dysprosium are used in metal-halide lamps because of their characteristic emission spectra in the visible range. Iodides, and sometimes bromides, of these metals such as sodium, scandium, indium, thallium, and dysprosium are chosen because they are easier to vaporize and ionize than the pure metals as such. Like the other high-intensity discharge lamps, the pressurized gas is maintained within the arc tube and the same mechanism of operation is followed for electron excitation and light emission. However, the outer casing is made of UV-filtering quartz glass to block the UV radiations of mercury. Since the light emitted by the lamp is a mixture of the radiations by the individual metals present in the vapor mixture, changing the combination of the metal halides allows the production of metal-halide lamps with various emission spectra [20].Metal-halide lamps have an evenly distributed spectral output and produce white light with a high luminous efficacy of 100–120 lm/W. metal-halide lamps can be used in plant growth applications due to its high PAR, relative high percentage of blue radiation, and energy efficiency of approximately 25%.

III. LIGHT EMITTING DIODES(LED)

Significant effects of light on plant growth have led to the use of additional light in undergrowth cultivation. Especially during winter months when the light intensity decreases, additional lighting has significant effects on plant growth [22,23]. The use of LED lights has become widespread in recent years for additional lighting before sunrise and / or after sunset [8,24,25,26,27].LED lighting allows the plant to grow in sunless hours[29]. The use of LED lights in different colors according to the development stages of the plants in the greenhouse vegetable cultivation has started to become widespread. For this purpose, red and blue LED light-emitting lamps are widely used and sold [27].

LED lamps, environmentally friendly, long-lasting and convection in electricity consumption compared to all light sources saving occurs because of their being used in many countries and Turkey are also increasingly being used [28,30,31]. LED lamps provide up to 65% energy saving compared to existing lighting technologies [25,28]. In addition, the average lifetime of a normal incandescent bulb is 1000 hours, while the lifetime of LED lamps can range from 20,000 to 50,000 hours. LED lamps provide illumination without damaging the plants as they do not emit ultraviolet or infrared radiation and the system does not contain mercury and lead [28].

LEDs emit light from a semiconductor diode chip. Although the emission of light from Incandescent lamps also occurs from a solid (filament), the cause of electromagnetic radiations is quite different from the LEDs. The Incandescent lamps emit radiations due to the heating up of the filament. LEDs emit light due to the transition of electrons from higher to lower energy orbital's. gas discharge lamps emit radiations due to release of excess energy from electrons too, but the source of energy is thermionic excitation due to the electric arc. In LEDs, the electrons are not impelled into higher excitation states. Simply driven by the electrical potential difference from a higher energy orbital to a lower one.

A LED is a solid-state semiconductor device. It emits light upon the flow of electricity, following the principle of electroluminescence. Electroluminescence is the emission of light when electrons driven by an electrical or magnetic field enter a lower energy orbital and release the excess energy in the form of electromagnetic radiations. The phenomenon was first observed by H.J. Round in 1907 while working with silicon carbide (SiC). Later, in 1955, R. Braunstein reported the emission of infrared radiations from various semiconductor alloys. James Biard and Gary Pittman (in 1961) of Texas Instruments accidentally discovered the emission of infrared radiations from gallium arsenide (GaAs) semiconductor upon the passage of electricity, while working on solar cells. In the same year, Nick Holonyak Jr. designed the world's first LED producing visible light (red) using a gallium arsenide phosphide (GaAsP) diode. Ten years later, Holonyak's student M.G. Craford designed the GaAsP-based yellow LED and high-brightness red and red-orange LEDs. In 1970, improvements in semiconductor fabrication and packaging techniques by Jean Hoerni and Thomas Brandt led to the drastic reduction in the cost of manufacturing LEDs. Initially, the development of light-emitting semiconductor technology was associated with red and infrared radiations. The lack of a viable blue LED hindered the utilization of this technology to plant growth applications. H.P. Maruska designed the first blue LEDs based on gallium nitride (GaN) in 1972. In 1994, Shuji Nakamura presented themdesign for a high-brightness blue LED employing an indium gallium nitride (InGan) diode. The newly developed LED with a peak emission wavelength of 450 nm was found to be suitable for use in studies on plant growth and development. The wavelength matches with the maximum absorption peak of plant photoreceptors of carotenoids[18].

Various semiconductor materials have been used since Holonyak'sGaAsP-based model for fabricating red, green, blue, and white LEDs. Choice of the semiconductor alloy was guided by the need to increase the range of emission wavelength and luminous efficacy of the new LED as compared to its predecessors. Further enhancement in luminous output and power efficiency could be attained by increasing the efficiency of radiative recombination (electron–hole pairing leading to photon emission) within the LEDs. This was achieved via bandgap engineering by the use of heterostructures and quantum wells. Advancements in epitaxial crystal growth techniques enabled the formation of customized heterostructures and quantum wells in LED chips [32].The technology led to the development of power-efficient high-brightness LEDs that have sufficient luminous output with desired wavelength to sustain optimal plant growth. Such LEDs are made from binary direct bandgap alloys from groups III–V elements of the periodic table, namely aluminum gallium arsenide (AlGaAs), aluminum gallium indium phosphide (AlInGaP), and aluminum indium gallium nitride (AlInGaN). Availability of high-brightness LEDs with spectral output matching with the action spectra of photosynthesis and photomorphogenesis created the platform for the LED-based plant illumination system [33].

We know that LED luminaries can become the smart solutions for sustaining plant growth in controlled environment agriculture and regulating morphogenic responses in plant tissue culture.

A. Working Principle of LED

The LED comprises a semiconductor chip housed within an epoxy or plastic lens, with connecting wires for directing the electrical current. The chip is a small (approximately 1 mm2 in size) semiconductor wafer that has been impregnated with specific impurities or dopants (n types and p types). n-type, i.e., elements having a high number of valence electrons, and p-type, i.e., elements having a high number of empty slots or "holes" in the valence shell. The p-type- and n-type-doped semiconductor crystals are fused together to form a "p–n heterojunction." As the electric current moves across the diode from the p-side to the n-side, electrons from the n-side cross over to the p-side. These electrons now fall into the vacant spaces in the orbitals of the p-type dopant resulting in "electron-hole pairing."

As the energy of the newly acquired orbital is lower than the energy possessed by the electron, the excess energy is liberated as electromagnetic radiation having a specific wavelength or color. This wavelength corresponds to the difference in valence shell energies of the p and n dopants. The phenomenon can be mathematically expressed as DE = (hc)/k (DE = change in energy of an electron, h = Planck's constant, c = velocity of light, k = wavelength of light). By virtue of its constituent dopants, an LED is capable of emitting light at a fixed wavelength only.

The application of red and blue monochromatic LEDs alone or in combinations has been reported for plant morphogenesis both in vivo and in vitro over the decades [34,35,36,37]. However, such LED lighting suffers from the waveband mismatch with the photosynthetic action spectrum and the high fabrication cost of the complicated circuit. Such LEDs are called trichromatic or tetrachromatic depending upon the combination of monochromatic LEDs used. White LEDs made by red, green, and blue LED clusters have a tunable spectral output controlled by the drive current through individual red, green, and blue LED units [38]. Phosphor-coated blue and UV-LEDs are the preferred source of white light owing to their common availability at low cost. However, the initial phosphor-coated LED models suffered from significant energy losses at the phosphor due to low energy conversion efficiency [39]. Approaches are being made to develop high-efficacy white LEDs using a hybrid model which includes colored phosphors along with monochromatic LEDs. A decrease in total internal reflection within the chip and device encapsulation with multicolor-emitting phosphors could enhance the luminous efficiency [40]. Recently, Chen et al. [41] proposed the potential of Eu+-doped fluorophosphate in fabricating white LEDs for application in plant growth.

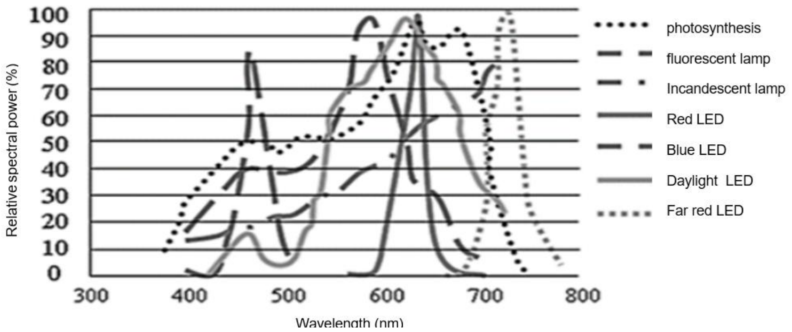

Figure 4. Characteristic of the photosynthesis and the artifical light sources[42]

B. Features of LED

Lamp features such as spectral quality, luminous efficacy, power requirement, life span, heat emission, robustness, and ease of disposal is some features of Lamp. They are discussed in the below for assessing the performance of each lighting system.

Plants absorb radiation mostly in the 400-700 nm visible range and convert CO_2 uptake and water into oxygen and glucose. The amount of absorption in each wavelength depends on the cellular structure of the plant and may differ from species to species somewhat.

Another important parameter is Daily Light Integral which is defined as the total number of photons impinging per square meter in one day. DLI is measured in units of mol/m².d and each plant has a specific requirement of DLI for its growth. Values ranging between 6-18 mol/m²/d are common depending on the particular plant.

There is a relationship between PPFD and DLI which is given by:

DLI=PPFD x light hours per day x (3600/1000,000).

You can see from this formula that there is a trade-off between PPFD and number of light hours required to achieve a certain DLI value. If there is a certain amount of natural lighting available for a green-house, it has to be subtracted from the original DLI value for proper artificial lighting fixture calculations. Taking into account the DLI, PPFD and number of light hours per day, you can calculate the total number of fixtures required in a green-house to illuminate the crops.

In Greenhouse, Vegetative Growth (Leafy Greens/Herbs)is minimum 17 mol/m²/d

Flowering Crops (Peppers/Tomatoes): 20-40 mol/m²/d

In Indoors, for microgreens it is 6-12 mol/m²/d and for Vegetative Growth (Leafy Greens/Herbs) is 12-17 mol/m²/d. For flowering Crops it is 15-40 mol/m²/d [51]

We know that for plant growth availability of a proper light environment is pivotal. Incident spectrum and photon flux density (PFD) are two major factors that govern plant development in response to the lighting conditions. Plants essentially utilize the infrared, red, and blue portions of the incident spectrum for conducting photosynthesis and regulating numerous developmental and adaptive processes. Chlorophylls absorb photons and utilize the energy for photosynthesis [43].The main absorption peaks of chlorophyll are located in the red (625–675 nm) and blue regions (425– 475 nm). Carotenoids, the auxiliary photoreceptors of chlorophyll, absorb light mainly in the blue region. Photomorphogenic responses including germination, phototropism, leaf expansion, flowering, stomatal development, chloroplast migration, and shade avoidance are regulated by three types of photoreceptors, viz. phytochromes, cryptochromes, and phototropins[44,45,46].Interconvertible forms of Pr and Pfr in the red at 660 nm and in the far-red at 730 nm, respectively, constitute the phytochrome photoreceptor system. Phytochrome-mediated photomorphogenic responses are critically regulated by the sensing of R/FR ratio [47].The pigments absorbing blue light include both cryptochromes (cry1, cry2) and phototropins (phot1, phot2).

Cashmore et al. reported [48] that the cryptochrome system controls several aspects of morphological responses, such as germination, leaf expansion, stem elongation, and stomatal opening. It also regulates the circadian rhythm in flowering plants.

Phototropins are involved in the regulation of pigment content and the positioning of photosynthetic organelles in order to optimize the harvesting of light and to prevent photo inhibition[49].

Insolation contains all the regions of the visible spectrum along with radiations in the infrared and UV regions. Intensity of solar radiations is relatively higher in the blue-yellow (460– 580 nm) range. Like sunlight, all conventional electric lamps, viz. Incandescent lamps, fluorescent lambs, and high-intensity discharge lamps, are broad-spectrum light sources. The Incandescent lamps have a continuous emission spectrum having high proportions of photons in the infrared and red ranges, the PFD gradually reducing toward blue. Due to the presence of phosphor coating, white fluorescent lambs also have a continuous visible spectrum with peaks near 400–450 nm (violet-blue), 540– 560 nm (green-yellow), and 620–630 nm (orange-red) that results in a balanced white color rendition. High-pressure mercury lamps employing phosphor coatings also feature a similar emission spectrum but with sharper peaks than fluorescent lambs. Spectral emission of high-pressure sodium lamps exhibits peaks in the 560–610 nm (yellow-orange) region which imbues these lamps with a predominantly yellow light output. Metal-halide lamps emit a continuous visible light spectrum with several peaks distributed evenly across the entire spectrum. Fluorescent lambs, high-pressure mercury lamps, and metal-halide lamps are capable of delivering bright white light and are hence also referred to as "daylight lamps."

LEDs are essentially monochromatic light sources. They have a specific emission wavelength this feature is determined by the constituent elements of the LED chip. A wide variety of light spectra can be obtained from LED-based luminaries by simply embedding specific LEDs for the desired wavelengths. All conventional artificial light sources have significant emissions in regions of the visible spectrum that plants simply do not require. Since electrical lamps produce light at the expense of electrical energy, delivering wavelengths of light that are not utilized by the plants becomes impractical. Also they are not economic. With LEDs, it is possible to produce artificial light with selected peak wavelength emission that closely matches the absorption peak of a known important photoreceptor. Furthermore, the designs of Incandescent lamps and gas-based electrical lamps do not allow the regulation of operating light intensity. Intensity of emission from LED lamps can be easily regulated by altering the electrical current. Thus, it is possible to construct LED panels with specific peak emission that are utilized by plants, having intensity control for adjusting the PFD most suited for the plants being raised. In this way, customized LED luminaries would allow a versatile control of radiation intensity and spectrum (Fig. 5).

Efficient conversion of electrical energy to light energy is an important factor. It used in the selection of the light source for indoor plant cultivation. The luminous efficacy of artificial light sources is a measure of luminous flux produced by the lamp per watt of electricity consumed (lm/W). It must be noted that luminous efficacy takes into consideration only the spectral output in visible range. Thus, lamps emitting significant amounts of radiations in the infrared and ultraviolet regions tend to have lower luminous efficacies compared to others. Power requirement of a lamp refers to the wattage supply required for operating the lamp. The lower the power requirement, the cheaper and easier it is to run any electrical lamp.

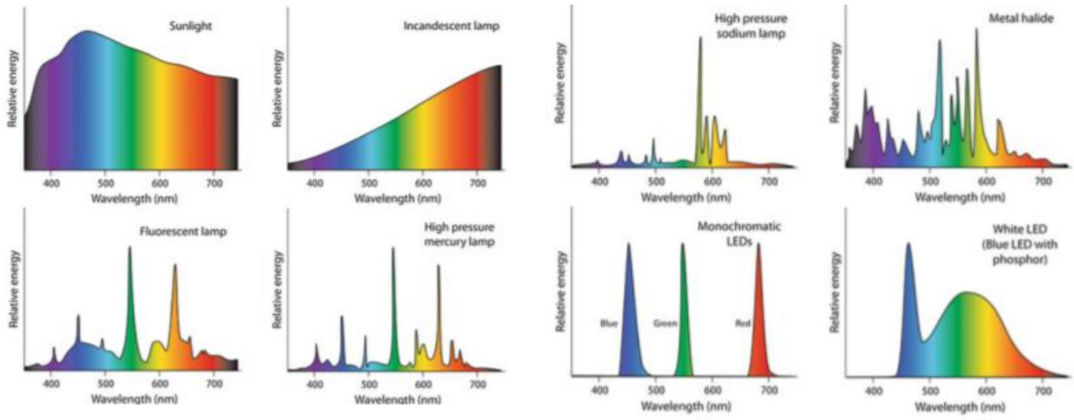

Figure 5. Spectral outputs of the various light lamps[18]

Among all artificial light sources, high-pressure sodium HPS and metal-halide lamps have the highest luminous efficacies. However, if we consider the lumens utilized by plants, the value gets reduced significantly since only the blue and red regions must be considered for plant use. The useful luminous output of even the most power-efficient electrical lamps may be considered to be quite low for plant growth. Although the luminous efficacies of conventional light sources have improved significantly since their initial development, the values attained plateau in the range of 80–125 lm/W. LEDs with luminous efficacy of 80–150 lm/W are already available in the market. Combinations of monochromatic LEDs can also be used to produce specific spectra that may be completely utilized by the plants, thus making the useful luminous output equivalent to the total luminous output. Further, due to rapid advancements in LED lighting technology, it is expected that LEDs with an efficacy of >200 lm/W will be developed within the next few years. The power requirement of a typical LED is 10–100 times less than most conventional lamps, thus making LED lamps highly cost-effective. Since LEDs consume less electricity, application of this technology shall also reduce the pressure on fossil fuel reserves used for generating electricity.

Dissipation of heat from the lamp is undesirable for indoor farming as well as for in vitro propagation from various aspects. Artificial light sources generating a lot of heat tend to raise the ambient temperature, a situation which may affect the quality of crops and the process of morphogenesis during in vitro culture. Additionally, this increases the load on the cooling system used for maintaining the temperature, leading to an increment in the electricity consumption. Furthermore, such light sources need to be placed at a safe distance from the crops/cultures as direct exposure to the heat may prove to be fatal. In vertical farming models where the crops are grown in tiers, using light sources having lower surface temperatures allows the placing of crops closer to the light source, thus giving more space for constructing more tiers and obtaining a higher yield per volume of the farming space. This notion is also applicable for in vitro culture. Dissipation of heat to the surroundings during any form of energy conversion has been considered as a loss of energy from the system. Since light sources having cool operating temperatures lose lesser energy to the surroundings in the form of heat, they are able to convert electrical energy to light energy more efficiently.

Inelastic collisions of electrons occurring in Incandescent lamps and gas discharge lamps liberate a lot of heat energy, a condition absent in LEDs. LEDs also generate heat due to their intrinsic resistance at the p-n junction. However, the heat generated is negligible as compared to that in the conventional lamps. Furthermore, incorporation of heat sinks in modern high-power LED designs allows the LED to keep on operating at cool temperatures even while conducting significantly higher electrical currents. They have a cool surface temperature and are safer for growing plants as they practically do not emanate any heat as compared to the Incandescent lamps and gas discharge lamps [50].

The overall operating cost is influenced by the lifetime of the luminaire. Because frequent replacement of a large number of lamps on a commercial scale involves a huge capital input on a regular basis. Because of the extremely high operating temperatures conventional lamps gradually wear out. LED components do not wear out easily and that extended its life span by several thousand hours from within owing to the low working temperature. As the IL and gas discharge lamp illumination units grow old, precipitations on the inner surface tend to make the lamp dim. Thus, despite the lamp functioning optimally, the luminosity produced by it gets reduced. LEDs are solid-state light sources that do not contain any vapors or gases nor involve vaporization of elements, hence eliminating the chances of dimming due to precipitations.

All conventional artificial light sources, by virtue of their design, emit light in all directions. The use of reflective coatings in fixtures reduces the loss of light within the fixture. However, the luminous flux or the total useful light obtained in the desired direction becomes significantly lower than the total light produced by the lamp. An artificial light source with directionality of light emission can be used to provide greater luminous flux to the plants with significantly lower fixture losses. An LED contains a reflective cavity housed within the epoxy cover that concentrates all the photons in a single direction. Furthermore, half-isotropic spatial pattern of LEDs makes them directional emitters. LEDs with a small viewing angle and the use of secondary optics such as collimator lenses can improve the luminous efficacy by directing the light toward the plant canopy.

One factor that increases the desirability of the lamps is their small size and robustness. Small lighting units occupy a small volume, allowing more space for growing products, especially in vertical farms. Further, lamps made of durable materials are easy to handle and thus more user friendly. Artificial light sources devoid of hazardous materials such as mercury are preferable from the point of view of disposal. Incandescent lamps and gas discharge lamps are made up of different types of glass filled with various gases. Users have to exercise caution while handling such lamps. gas discharge lamps contain mercury which is highly toxic when released in the environment, making the disposal of spent gas discharge lamps a matter of concern. High-intensity discharge lamps are under high pressure at the operating level, making them unsafe where there is a production error. They are often large Luminaires for such lamp make them uneconomical in terms of space. On the contrary, LEDs are small, solid-state lamps housed within epoxy or plastic lens. LEDs are not only more robust and easy to handle, but also occupy a very small portion of the space being utilized for growing plants. If we evaluate LEDs in terms of plant growth and development compared to traditional electrical light sources, the advantages can be listed as choice of the peak emission for customized plant growth and development, Versatile control of the flux emission and the light spectrum, High luminous efficacy, Small size and directional light emission, Long life expectancy, Negligible heat emission, Does not get dim with age, Economical in terms of space and power (wattage) requirement, Plastic body, hence more robust and easy to handle, and Easy to dispose without any environmental hazards.

IV. Results

Incandescent lamps, fluorescent lambs and the different high-intensity discharge lamps, have been employed in agriculture. Advancements in lighting technology have allowed the implementation of

electrical lamps for controlled environment agriculture and growing plants. High-power requirement and relatively short life span of these lamps made such crop production systems highly uneconomical. Although the various conventional electrical lamps used for agricultural lighting have the capacity to boost the qualitative and quantitative yield of the plants, they all suffer from certain limitations. Energy conservation is one of the major concerns in controlled environment, using traditional lamps, especially in northern latitudes. Continuously LED technologies have been developed. This advancements in the LED technology over time including packaging, current drop, phosphor coatings, intelligent control of light distribution, intensity and spectral quality along with the reduction in prices will make LED-based illumination system a smart choice for novel open as well as closed plant production systems.Emergence of solid-state lighting has not only offers the energy-efficient interior agriculture but has also opened up new frontiers for studying plant response to a specific wavelength and radiation quantity. LEDs have been adopted as a new source of artificial lighting to promote photosynthesis, regulate photomorphogenesis and improve the nutritional quality of leafy vegetables.
It is now possible to grow strawberries in the middle of winter thanks to LED technology indoors. Thanks to the LEDs that can be adjusted at the desired wavelength, the way of growing agricultural products with the desired characteristics is opened. For people who want to do winter farming, they prefer hydroponics (indoor farming) and buy some high-tech hydroponic pots illuminated by full-spectrum growth lights, and some even design their own systems. Plants are grown five times faster and naturally with systems with ideal climate created with LED lighting and water tanks. In other words, agricultural products develop rapidly and save energy. In addition to these, LED products are more durable than other broad-spectrum lighting products, thus saving on fixed costs.
Although some experts say that LED has benefits in agriculture, it should not be forgotten that the effect of LED technology on human health and nature is not known yet and it may lead to some risky situations. On the other hand, daylight is a must for vitality life. Another question is whether agricultural products grown with LED have the same taste and quality as those grown with daylight.
As a result, plant / greenhouse lighting with LED light sources will contribute to agricultural production and economy with many advantages. In addition to energy savings, as with any project, it will provide additional monetary savings with reduced maintenance costs and long lamp replacement times provided by the long life advantage.

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