LED Lighting in Horticulture

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In

PHYSICS

By

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CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled **"LED Lighting in Horticulture",** in partial fulfilment of the requirements for the award of degree of Master of Science in Physics submitted in School of Physics and Material Science at Thapar Institute of Engineering and Technology, Patiala (Punjab), is an authentic record of my own work carried out under the supervision of **Dr. Soumendu Jana** and refers other researcher's work which are duly listed in the reference section. The intellectual content of this thesis is the product of my own work and contains no material which to a substantial extent has been accepted for the award of any other degree of this or any other educational institution, except where due acknowledgement is made in the thesis.

Jagmeet Kaur

Date: 28-06-2018 (Jagmeet Kaur)

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It is to certify that the above statement made by the candidate is correct and true to the best of my knowledge and belief.

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Acknowledgement

Research is a wonderful experience and successful completion of research work has been associated with the blessings of Guide.

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Words are too inapt to express my feelings about ***my Parents****. They have been my beacon light, friend, philosopher and guide alike. I have received infinite selfless love and economic security from them .I have been able to see this day in my life because of their unflagging love, countless sacrifices and trust on my abilities which made it possible for me to go through various phases of my life. No words are there to express their love and sacrifices.*

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Jagmeet Kaur

Jagmeet Kaur

ABSTRACT

LED based lighting is designed by using Mathematical Equations in numerical Programming, consisting two different coloured LEDs, i.e., red and blue. Using the theoretical results we designed the actual panel in which the LEDs are arranged in such a way that the plants placed under the LED panel can get uniform illumination. It is an improved version as it can provide stage specific lighting and crop specific lighting i.e. the intensity of light can be altered accordingly.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

Light is crucial for the growth of plants. Sunlight is the least expensive source available, however for horticulture it isn't always feasible in adequate amounts. Several sources of supplemental lighting are being used for research purposes alongside plant cultivation. On account of the properties of LED lighting and significant advances in our comprehension of plants, we now have huge possibilities to tune the light to help yield, alter the plant attributes and keep up plant wellbeing. In this manner, the utilization of artificial light has turned out to be very common keeping in mind the end goal to expand quantity and quality of plants. The feature which makes this innovation a standout amongst the most critical advances in plant lighting is that amount of heat released is very less making them highly efficient in producing better lighting.

1.1 HORTICULTURE

Horticulture is a technique of growing and managing the fruits, nuts, vegetables, herbs, flowers, woody ornamentals and turf. In this practice, plants are conserved and preserved along with restoring of landscapes.

The horticulture differs from agriculture in various aspects such as area of field, type of plants, environment etc. Horticulture is practised on relatively smaller crop fields as compared to agriculture. Moreover, multiple crops of plants are grown in gardens or patches in horticulture unlike agriculture where usually one major staple crop is produced. Horticulture can be done in an enclosed environment as well as in open-air.

Horticulture includes three major parts:

- Plant growth and maintenance
- Crop production
- Plant breeding

Figure 1.1 Indoor Horticulture

There exist four specific types of horticulture:

- Floriculture: It involves production and marketing of flowers.
- Olericulture: In this practice, vegetables are produced and marketed.
- Pomology: It is the process of producing fruits.
- Landscape: It involves maintenance as well as production of landscape plants.

Today, horticulture is focused on discovering new and environment-friendly ways of managing plants, improving the quality and quantity of crops and prevention from pests. One such practice involves the introduction of LEDs as a source of supplemental light.

1.2 ROLE OF LED LIGHTING IN HORTICULTURE

Artificial lighting is becoming an integral part in the field of agriculture, since not only the quality of the product obtained is better but it also increases the production , and most importantly it makes cultivation possible even in areas where natural light isn't plenty enough for production. In the beginning of 21st century LEDs were proposed in this field as an alternative to traditional light sources because it's more profitable. LEDs cut off the expenses of lighting and cooling as they are more efficient when it comes to use of electric energy to convert it into light energy and unlike other conventional light sources, the cooling loads are much lower. Moreover, the spectral distribution of LEDs can be easily manipulated [12]. These are a plausible substitute to existing lighting system because they have selective spectral out-put, they consume less energy, and have a long functional life. LED-based lamps of several different types are introduced in markets for plant production recently.

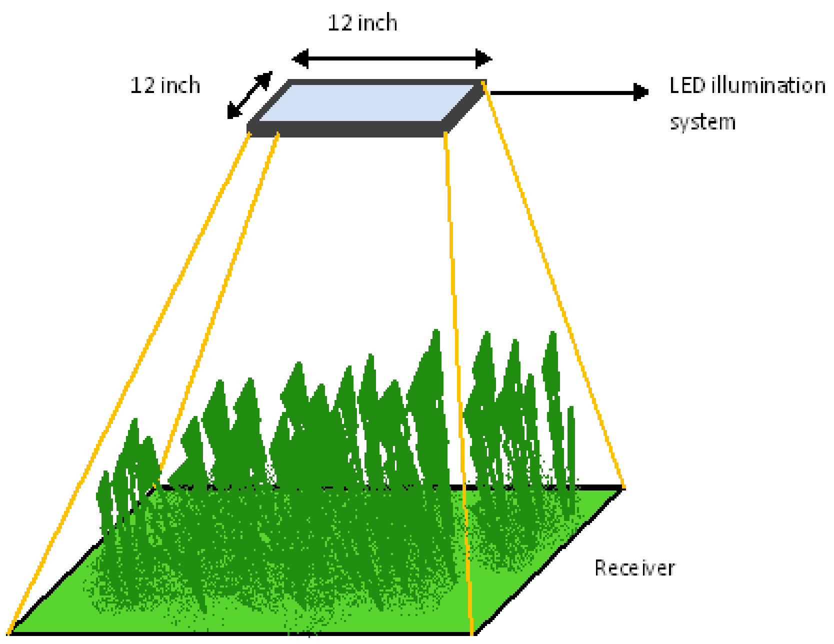


Figure 1.2 Plants growing under LED Panel

In this method, there is an extra expense of supplying artificial light in comparison to cultivation under natural sunlight. In accordance to this, the issue of quality and quantity of the product is considered important. While using LEDs, maximizing productivity is an issue to be concerned about because there exist certain economic constraints. Every crop needs different light configurations, from previous studies it is concluded that while determining the yield optimal red and blue ratio of LEDs have greater relevancy. LED lighting systems can be arranged over plants to improve light interception which in turn eventually increases the growth as per prior results, increased yield is associated with better light interception instead of increased photosynthetic rates. Phytochemical concentration in plants is highly affected by light. According to reports, using LED lamps in lettuce cultivation resulted in raising both growth and phytochemical traits. Some other experiments also demonstrated that LED lighting boosts the level of anthocyanin in grapes, tomato leaves and lettuce leaves, vitamin C in lettuce [12]. The quantity of NO3- in Indian mustard has also been decreased after using LED lighting systems. The degradation of various compounds that reduce the nutrient utilization in crops is indeed of the utmost importance, because such compounds, like nitrate in leafy vegetables can be life threatening for people of all age groups.

1.3 LITERATURE REVIEW

In 2013, Ki-Ho Son and Myung-Min Oh examined the green leaf lettuce and red leaf lettuce. Different ratios of red and blue LEDs were adopted to study the effects on shape of the leaf, growth of the plant and antioxidant accumulation. Exposure to 100% red LED resulted in elongated leaf shape as compared to other treatments while increasing blue LED had a negative effect on the growth of the plant [8]. One year later, Chang C. L. et al. introduced different lighting techniques using LEDs for various stages of growth of lettuce leaf. The variation in method of lighting effected the leaves count, length of leaf, fresh and dry weight, content of chlorophyll-a and nitrate[9]. Furthermore, in the year of 2015, Choi, H.G investigated strawberry in terms of quality of fruit and traits of growth in the presence of red and blue LEDs and their combination placed in (a) growth chamber (which solely had LED as source of light); (b) greenhouse (with additional lighting provision) [10]. In growth chamber, petiole length, width and length of leaf increased under blue LEDs while combination of blue plus red gave better results for same parameters in green house. C. Piovene et al. addressed (morphological, physiological and biochemical elements) the use of LEDs in producing sweet basil as well as strawberry in an enclosed environment. Most suitable spectra for these crops was found to be red: blue of 0.7 [12]. Whereas R.

Wojciechowska et al. evaluated the effects of sole red, red plus blue at ratio of 50:50, 70:30 and 90:10 on lamb's lettuce. In case of 90:10 yield of lettuce was highest [11]. In 2016, studies of T. Jishi et al. determined if the irradiation time of red and blue LEDs is shifted temporarily the growth of the cos lettuce plant is increased. The experiments conducted concluded that the factor responsible for growth-promoting effect was diurnal (of or during the day) PPFD change [13]. X.l. Chen et al. studied the effects of alternating red and blue lights on the nutrient content and growth of green oak lettuce in 2017. Interval of 8h: 1h accelerated lettuce growth in terms of height/width and leaf length/width. 8h: 8h & 1h: 1h promoted shoot biomass. 4h: 4h & 2h: 2h raised ascorbic acidic content while nitrate content simultaneously [16]. P.Morgan Pattison et al. analysed the efficacies of different packages of LEDs as well as loss in the luminaire channels followed by the studies of further improvement. It was said that maximum practical efficacy of phosphor converted LEDs could be up to 255 lm/W with further improvements while packages consisting mix coloured LEDs can reach the value of around 330 lm/W which will require breakthroughs on green and amber LED packages [15]. In 2018, F. Bantis et al. discussed regulation of various physiological and morphological parameters by using LEDs as a source of light for producing various horticulture species grown under green houses and growth chambers [18]. On the other hand, Q.c. Yang et al. examined the effects of red and blue LEDs by adopting their intermittent radiation on plant growth and accumulation of carbohydrate in lettuce [17]. Results showed increase in shoot biomass, higher fructose and sweetness as well as crispness was improved when it was exposed to 2 light/dark cycles of 8h/4h over a 24-h period. Hence, taste and the growth of lettuce could be easily changed.

Crops	LEDs used	Result on growth of plant	References
Banana	• Red (R) • Blue (B)	(80R:20B)-Yield and growth increased	Nhut et al. (2000)
Strawberry	• Red (R) • Blue (B)	(70R:30B)- Yield and growth increased.	Nhut et al. (2003)
Grapes	• Red (R) • Blue (B)	Rate of photosynthesis increased due to blue LEDs. Length of shoot increased due to red LEDs	Heo et al. (2006)
Tomato	• Red (R) • Blue (B)	Reduction in stem length.	Nanya K et al. (2012)
Cabbage (Chinese/Napa)	• Red (R) • Blue (B)	Blue LEDs increased chlorophyll and vitamin C content	Li H et al. (2012)

Table 1.1 LEDs' effect on different crops

1.4 GAPS

At present fluorescent lamps are being used on a large scale in the field of horticulture. These consume high electricity while light energy emitted being low which results in increased per plant production cost. However, this trend is changing with the introduction of LEDs in market.

But available LED lighting systems for horticulture are expensive. Moreover, these are not suitable for the crop specific lighting and stage specific lighting.

1.5 MOTIVATION

A proficient source of light is needed to lessen expenses and enhance plant quality and quantity. Latest progresses in this field of lighting have given us exceptionally productive sources of light as LEDs.

Moreover, a lighting system that can be suitable for various crops and at various growth stages has not been introduced into Indian markets.

1.6 OBJECTIVE

- Design and fabricate an LED panel for uniform distribution of light.
- Tune the intensity of the fabricated LED panel for crop specific purpose and stage specific purpose in horticulture.

CHAPTER 2

BREIF DESCRIPTION OF LEDs

Light-emitting diode is a semiconductor diode which on passing current emits light. When p-type semiconductor is placed in direct contact with n-type semiconductor, p-n junction is formed within an LED. The direction of current flow is always from anode to cathode i.e. p-side to n-side. This leads to the interaction between electrons and holes which results in the emission of light energy in the form of a photon.

2.1 CHARACTERISTICS OF LED LIGHTING IN HORTICULTURE

Some of the important characteristics in LED lighting systems are discussed below:

2.1.1 WAVELENGTH OUTPUT

For plants, there are certain wavelengths that we've learned through experimentation are particularly important for photosynthesis, growth and development. The term PAR or photosynthetically active radiation is defined by the range of wavelengths that scientists have determined are important for plants, and it corresponds with the visible spectrum.

Within the PAR range, experiments have shown that certain wavelengths promote plant growth and some wavelengths may also hinder growth in some species of plants. Scientific experiments demonstrated that most important wavelengths for horticulture are red and blue.

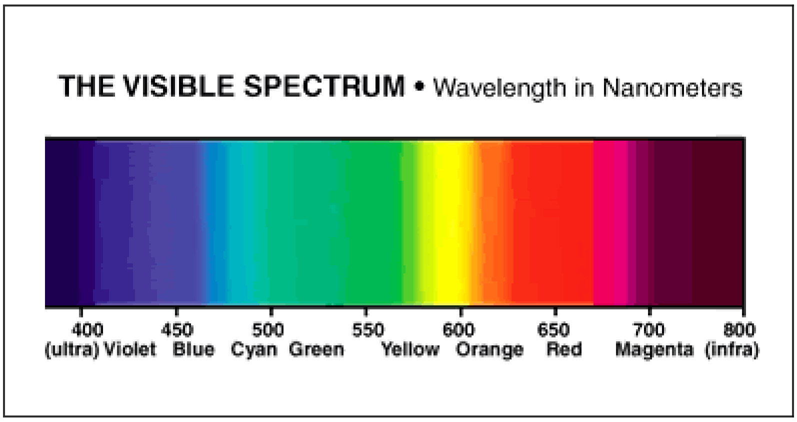


Figure 2.1 Visible Spectrum of Light

2.1.2 LIGHT OUTPUT

The light output of an LED light is not simply a function of Watt input. Instead, it is determined by the quality of its components and overall design. In fact, LEDs become less efficient as wattage increases because increased temperatures in the electronic circuit board containing the LEDs cause significant decrease in LED efficiency.
Here, the panel we have designed includes red and blue LEDs of 3 Volts each.

2.1.3 LIGHT INTENSITY AND HEIGHT OF PANEL

The relationship between light intensity and the distance from a light source is well understood by *inverse square law*. Light intensity is a standout amongst the essential measurements to know when relating grow lights.

When plants are grown in the presence of artificial light source the plants should be kept quite close to the light source, but one must be careful in doing so as relatively small distance between the plants and the light source could damage the plants with excessive heat.

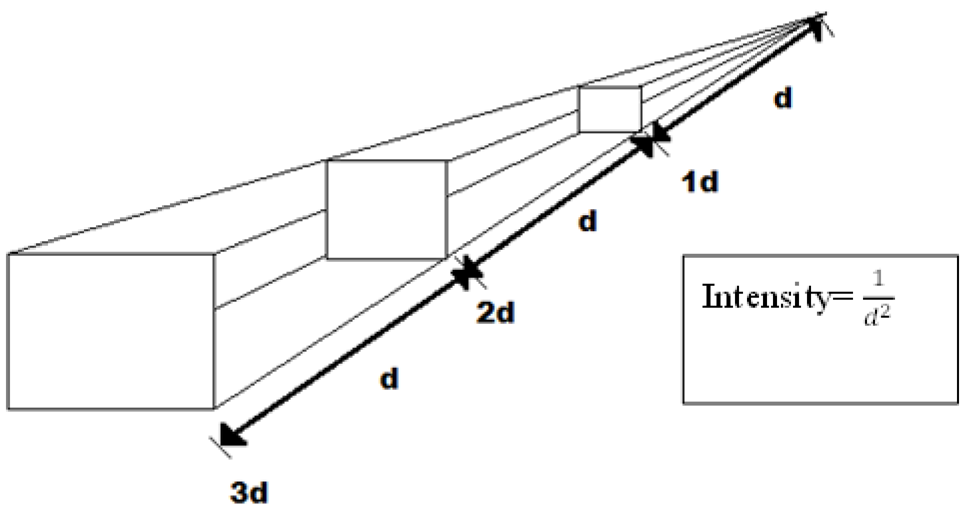


Figure 2.2 Inverse Square Law (varying intensity with distance)

Key highlights that make LED panels work exceptionally well include:

- The height of the panel should be adjusted according to the various stages of plant.
- The light output is uniform throughout the whole area underneath the LED light arrangement.

2.1.4 LED colour

The colour of an LED is a noteworthy factor. Usually a single colour is emitted by LEDs.

The peak wavelength determines the colour discharged by the LED and this is measured in nanometres.

Every diode must be fabricated by precise particulars to get the right wavelengths and retain its integrity with time. There exists various semiconductor compounds which are used to produce LEDs. Let us consider Aluminium Gallium Arsenide (AlGaAs) and Gallium Arsenide Phosphide (GaAsP), these are used to make Red coloured LEDs. Whereas Indium Gallium Nitride (InGaN) and Silicon Carbide (SiC) are used for Blue LEDs.

2.1.5 LED STRUCTURE

LEDs are basically electrical transformers developed and afterward encased in a transparent, hard plastic epoxy tar that ensures the LED and furthermore acts like a focal point.

Depending upon how the lens is fabricated, it might centre or spread light from the diode. A few sorts of lenses emit the transmitted light straight underneath the LED, while others utilize reflectors and diffusers to stretch out the light to a more extensive territory.

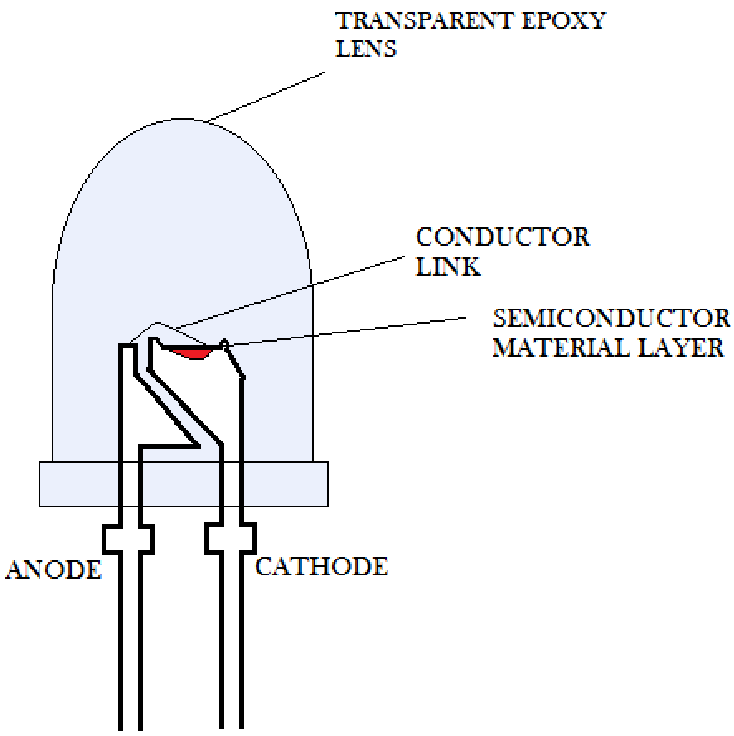


Figure 2.3 Internal composition of LED

2.1.6 WORKING PRINCIPLE OF LEDs

An LED is a p– n junction diode which on passing current emits light. Electrons start interacting with the holes when appropriate voltage is supplied which finally results in the release of light energy in the form of photons. It is the phenomenon known as electroluminescence. The energy band gap determines the colour of the LED.

- Usually aluminum-gallium-arsenide (AlGaAs) is the semiconductor material which is used in LEDs. The atoms in its ground state are strongly held and hence they do not conduct electricity.
- The doping of the material can be done by adding some impurities which disturbs the stability of material.
- In a semiconducting material, the impurities exist as extra atoms and this leads to two different situations i.e. either the free electrons will add up (N-type) to the system or the present electrons will be removed (P-type) leading to the formation of holes. This increases the conductivity of the material. When electric current is supplied in the N-type material, electrons will start moving from positive end to negative end whereas in P-type material they move from negative end to positive end.
- When the electrons jump within the levels of the semiconducting material a certain amount of energy is released which gives the intensity of emitted light.
- Electrons require some energy in order to jump from lower level to higher level. However, if the electrons existing in higher energy level release energy in the form of photons when falls to a lower energy level.

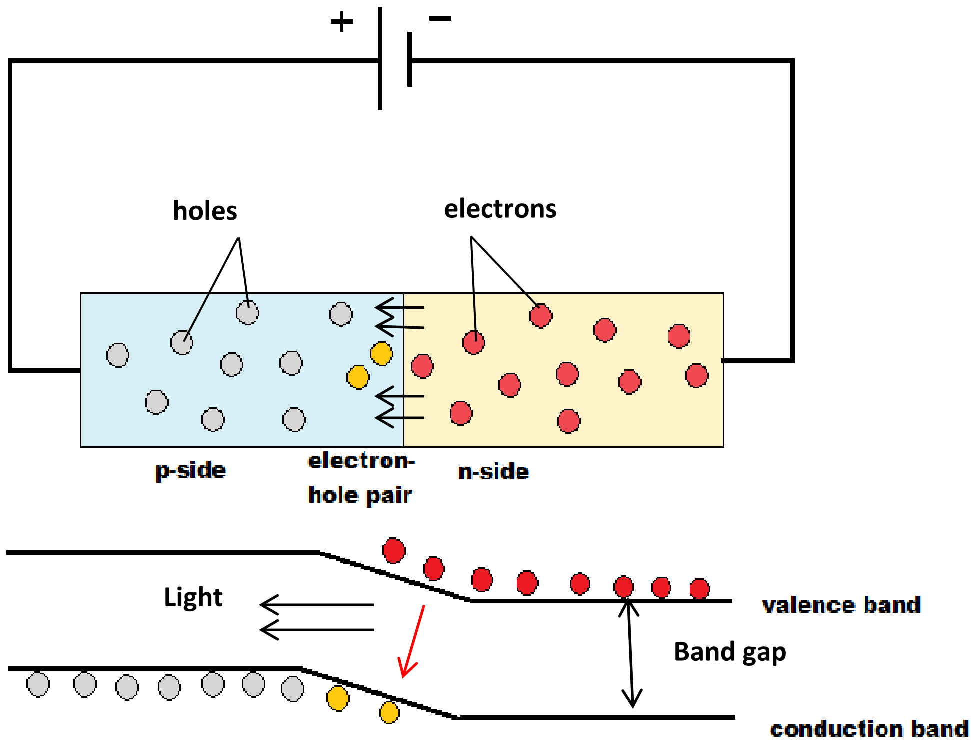


Figure 2.4 Principle of LEDs

2.2 MATHEMATICAL EQUATIONS IN LED PANEL PROGRAMMING

We mathematically design the panel of LED. For that we consider a 15 X 15 LED panel. Each of the LED has an amplitude profile given by the following equation:

$$\Psi = A\,exp\left(-\left(\frac{(X-l)^2}{a^2}+\frac{(Y-m)^2}{b^2}\right)\right)$$

l = distance between two LEDs along X-axis.
m= distance between two LEDs along Y-axis.
X=length of panel along X-axis.
Y=length of panel along Y-axis.
a = Profile width along X-axis.
b = Profile width along Y-axis.

The panel is designed according to the matrix form as shown:

11	12	13	14	15
21	22	23	24	25
31	32	33	34	35
41	42	43	44	45
51	52	53	54	55

Figure 2.5 Matrix representation of LEDs

2.3 DIFFERENT TYPES OF PANELS IN HORTICULTURE

Depending upon the type of crop to be produced, different arrangements using red and blue LEDs can be introduced. Using this concept three panels with different ratio of red and blue LEDs are designed. The following table shows configurations used in our study:

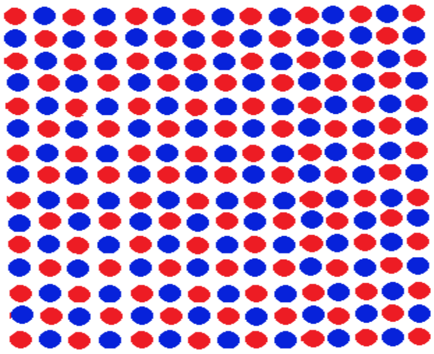
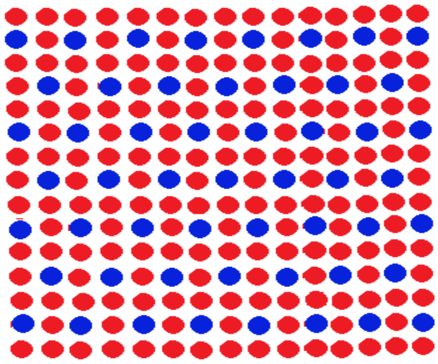
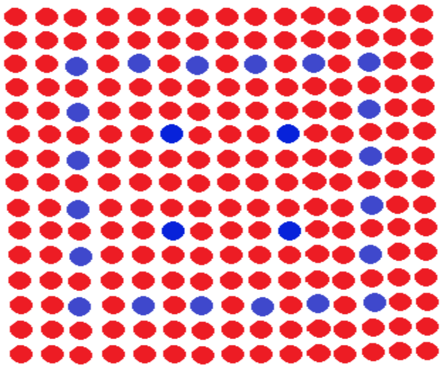
Panels	Number of LEDs	Ratio of Red and Blue LEDs	Arrangement
Panel 1	225 LEDs	Red : Blue 50:50	
Panel 2	225 LEDs	Red : Blue 73:27	
Panel 3	225 LEDs	Red : Blue 90:10	

Table 2.1 Different panels with different arrangement of LEDs

CHAPTER 3

RESULTS AND DISCUSSIONS

3.1 DESIGNING OF LED PANEL

LED lighting system is designed through MATLAB programming. We designed a panel in which whole light is uniformly distributed to the plants so that energy in the form of light received by plants is very high as compared to the existing lighting systems.

The dimensions of the panel are 12×12 inches. LEDs are arranged in the Matrix of 15×15.

The optimum distance between two LEDs is determined through programming.

Amplitude of both red and blue LEDs (A) = 3

To analyse uniformity as well as efficiency of designed lighting system, different intensity profiles are generated with several l and m values.

Figures 3.1-3.6 shows the effects of illumination performances for l and m values of 0.8, 1, 1.2, 1.6, 1.8, 2 respectively.

1. a=1; b=1;
l=0.8; m=0.8

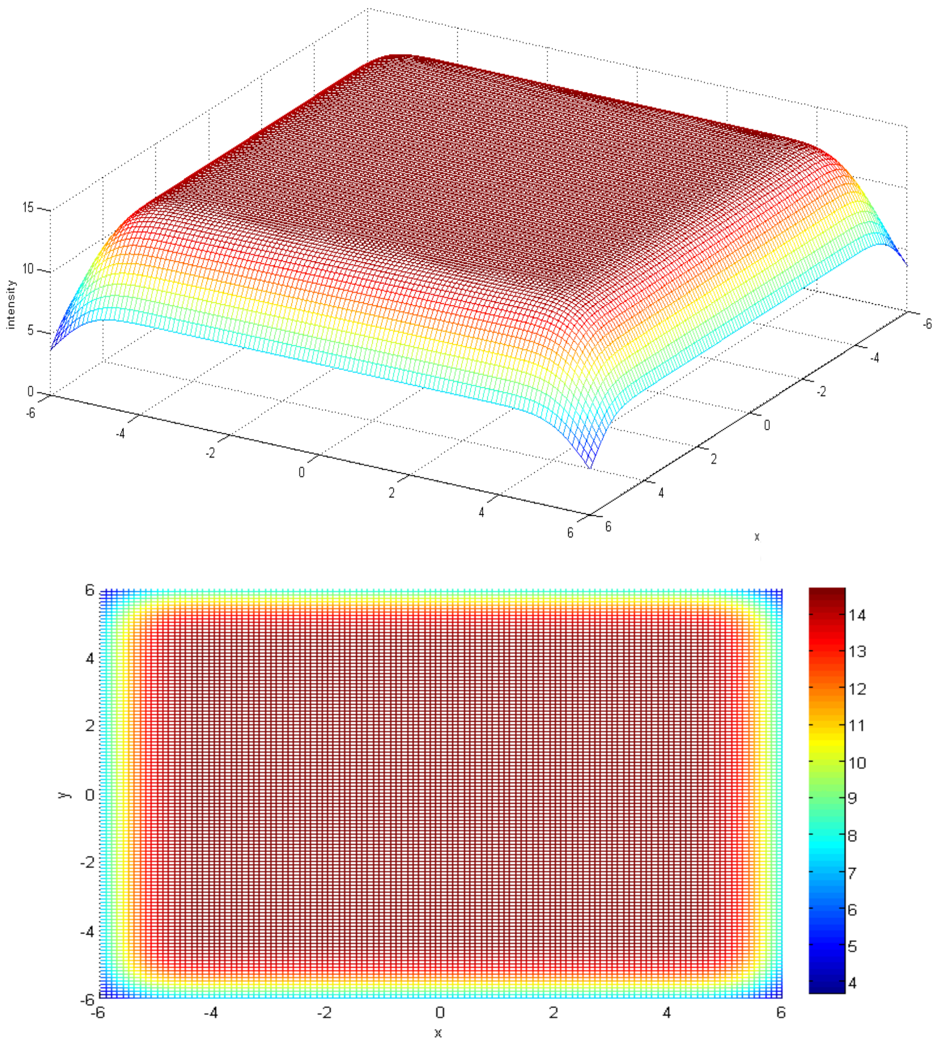


Figure 3.1 Intensity profile for spacing 0.8 inch

With the application of MATLAB a programme was built which provided uniform illumination based on distance between LEDs. Figure 3.1 shows the illumination pattern and performances for values l= 0.8 and m= 0.8, where l and m are distance between LEDs along X-axis and Y-axis respectively. Uniform distribution of light is obtained in this case.

2. a=1; b=1
   l=1;m=1

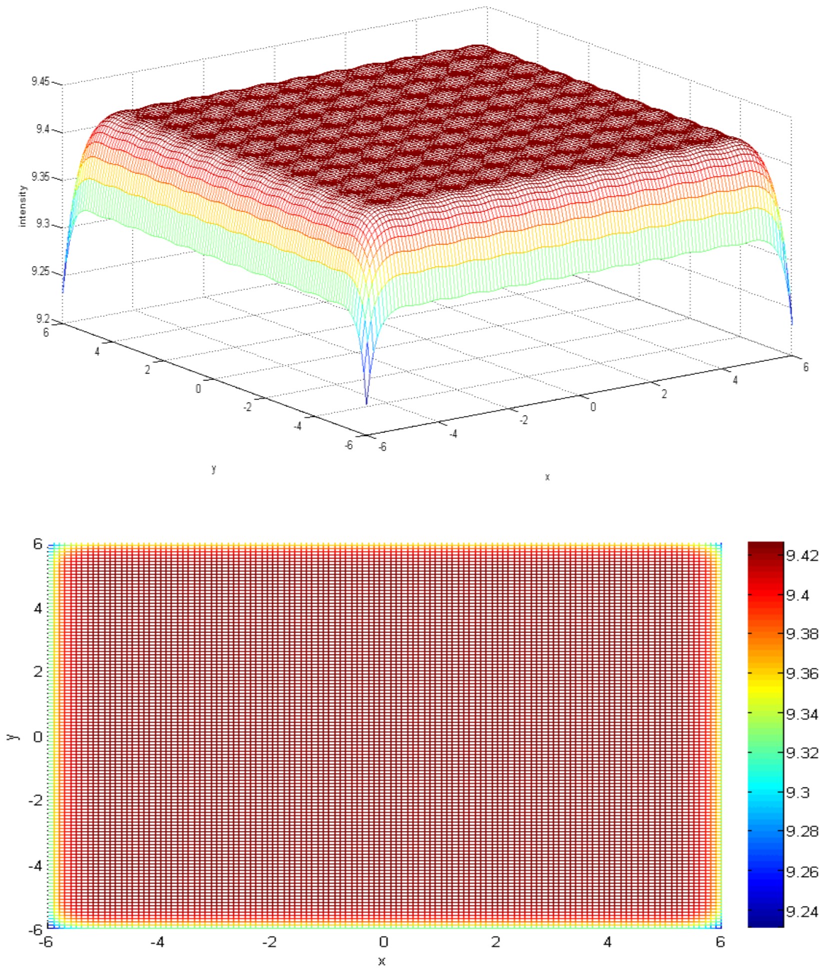


Figure 3.2 Intensity profile for spacing 1 inch

In this case LED-to-LED distance is increased by 0.2 from the initial distance along both axis. Figure 3.2 depicts the illumination pattern and performance for the values l= 1.0 and m= 1.0 along X-axis and Y-axis respectively. Almost uniform distribution of light is obtained. Therefore, this pattern can also be used to obtain uniform illumination.

3. a=1; b=1
l=1.2; m=1.2

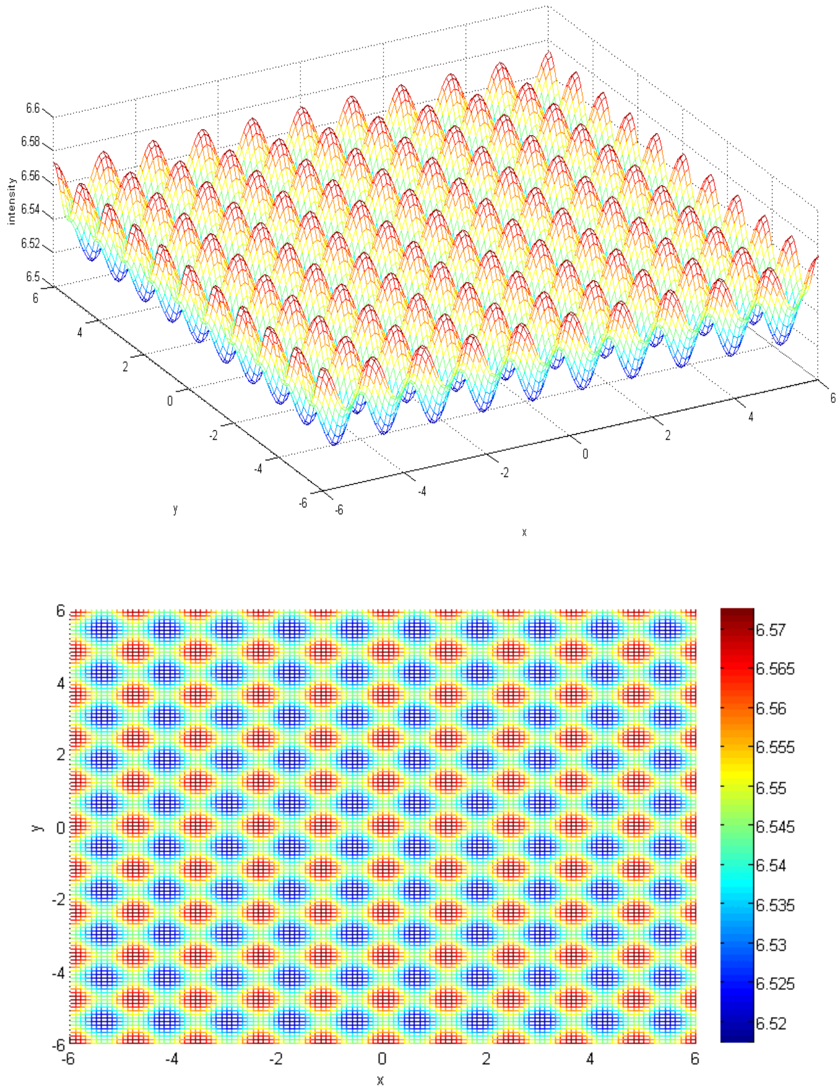


Figure 3.3 Intensity profile for spacing 1.2 inch

The figure 3.3 shows the illumination pattern and performance for the values l= 1.2 and m= 1.2 along X-axis and Y-axis respectively. The distribution of light is non-uniform under this case. The intensity is high right under the LEDs and decreasing in the gaps, Therefore, this pattern cannot be used to design an efficient panel.

4. a=1; b=1
   l=1.6; m=1.6

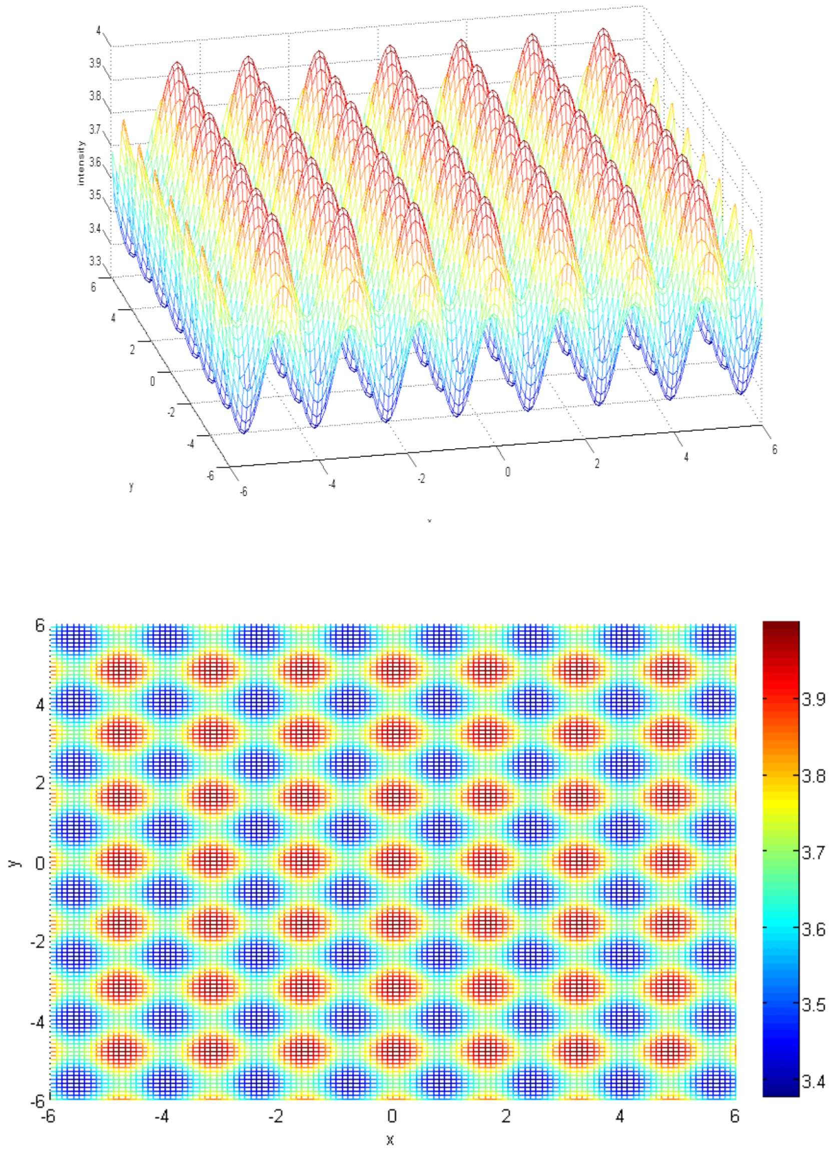


Figure 3.4 Intensity profile for spacing 1.6 inch

This case shows the illumination pattern and performances for the values l=1.6 and m=1.6 along the X-axis and Y-axis respectively. The pattern obtained is again non-uniform with intensity less than the previous one.

5. a=1; b=1
   l=1.8; m=1.8

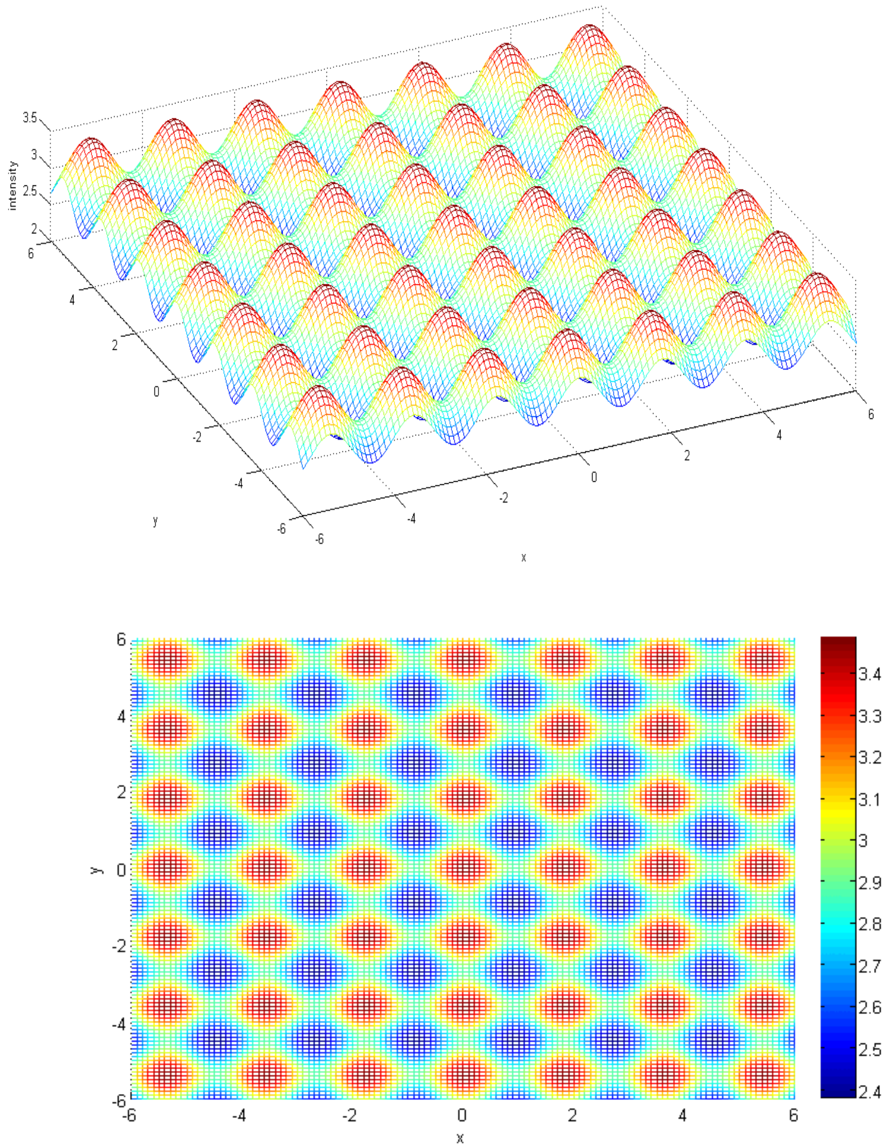
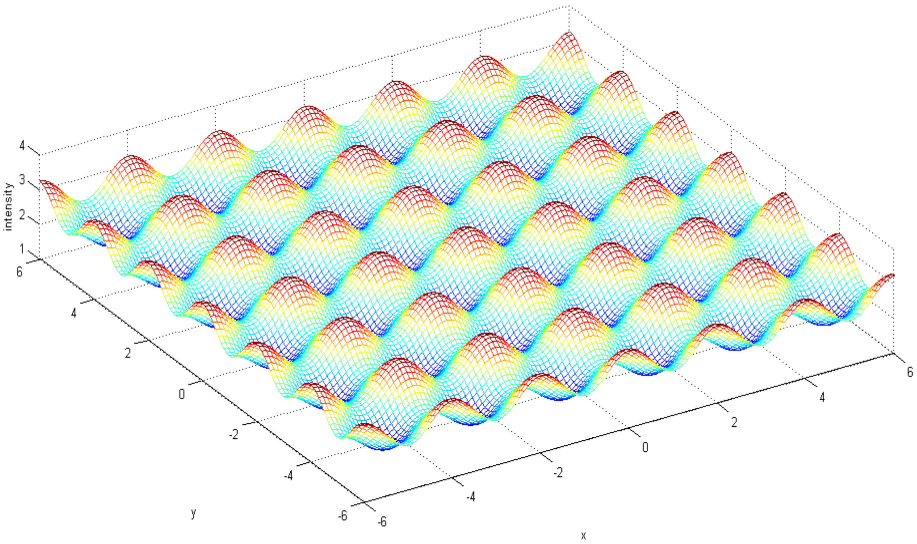


Figure 3.5 Intensity profile for spacing 1.8 inch

The above figure depicts the illumination pattern and performances for the values l= 1.8 and m= 1.8 along X-axis and Y-axis respectively. The light is distributed in non-uniform manner with intensity less than the previous ones which makes it comparatively less efficient.

6. a=1; b=1
   l=2; m=2



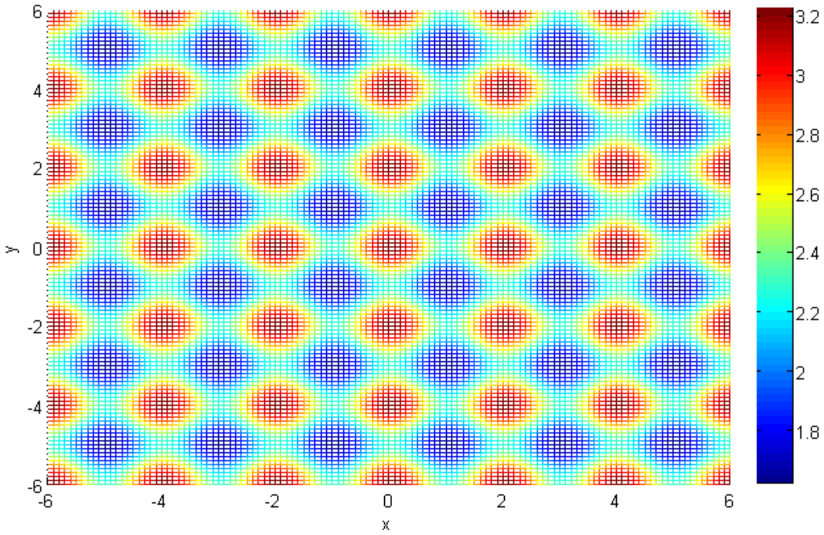


Figure 3.6 Intensity profile for spacing 2 inch

This figure illustrates the illumination pattern and performances for the values l= 2 and m= 2 along X-axis and Y-axis respectively. The distribution of light is non-uniform and intensity is minimum in this case. Hence it is not suitable for fabricating a panel with even illumination.

3.2 FABRICATION OF LED PANEL

We fabricated 2 panels each having an area of one square feet. A total of 225 LEDs were used in each panel which were arranged in 15 x 15 matrix form. Red and blue LEDs were used for fabricating both the panels with different configurations and ratios. The important components used are shown in the figure 3.7.

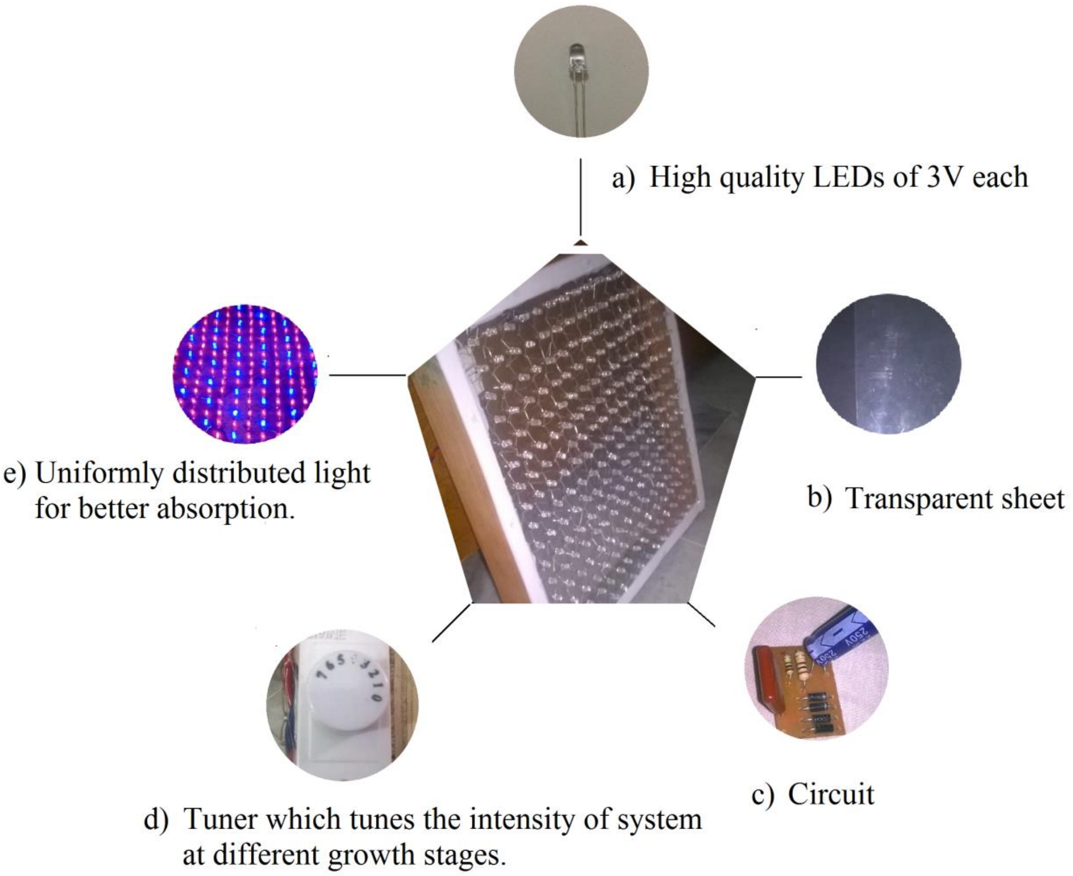
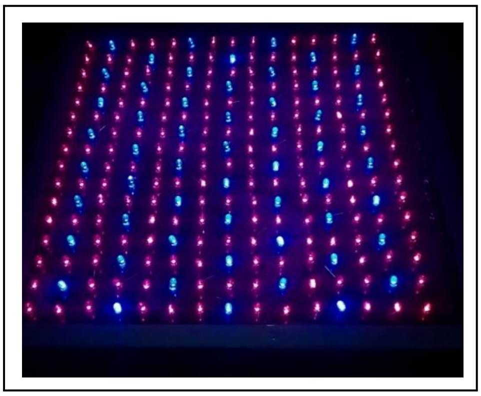


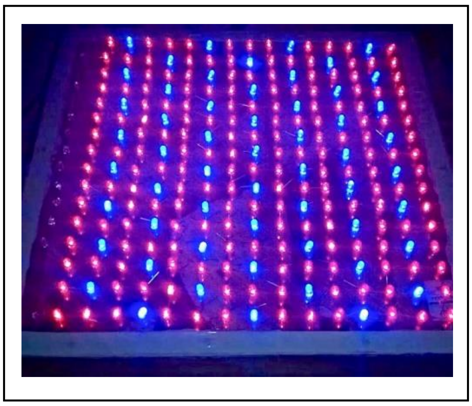
Figure 3.7 Components of LED panel

Panel 1

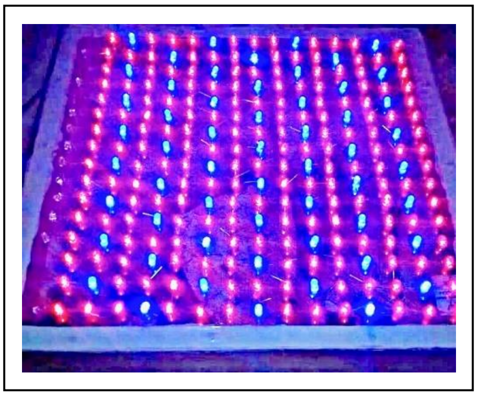
Ratio of Red and Blue LEDs used in this panel was 73:27. Odd columns were occupied by red LEDs while even columns consisted of alternate red and blue LEDs.



(a)



(b)

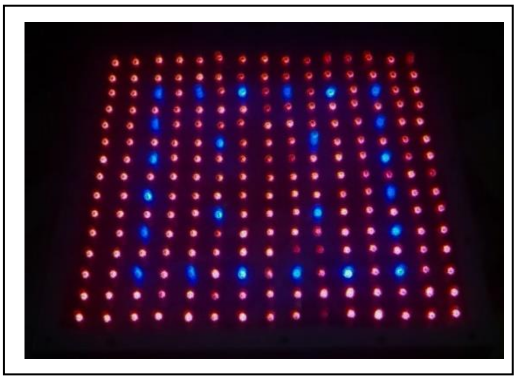


(c)

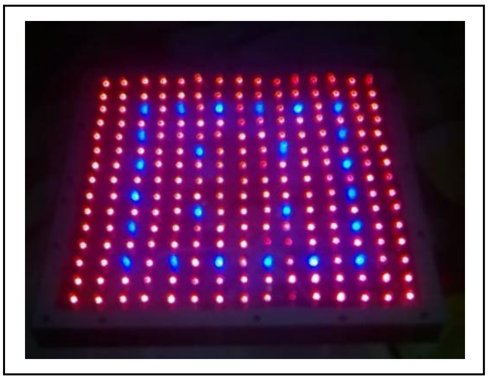
Figure 3.8 Varying Light Intensities of the panel 1 when knob of the tuner (a) positioned at 2; (b) positioned at 5; (c) positioned at 7

Panel 2

Ratio of Red and Blue LEDs used in this panel was 90:10. In this panel the blue LEDs were arranged at the centre of the panel as shown in figure 3.9.



(a)



(b)

(c)

Figure 3.9 Varying Light Intensities of the panel 2 when knob of the tuner (a) positioned at 2; (b) positioned at 5; (c) positioned at 7

This feature of varying intensity makes these panels suitable for various crops and different growth stages of the plant (seedling stage, vegetative stage and flowering stage).

3.3 SPECIFICATIONS

Dimensions: 12 x 12 inches

LEDs quantities: Panel 1- 165 red LEDs + 60 blue LEDs
Panel 2- 201 red LEDs+ 24 blue LEDs

Suggested Distance from the plant: 0.5-1.5m (20-60 inches) up to the growing stage of plants. At flowering stage the distance should be 8-12 inches.

Working Time: 10-12h

Brightness ratio: Panel 1- 73:27
Panel 2- 90:10

Input voltage: AC 110-220 V

Body material: Transparent fibre sheet

3.4 CONCLUSION

LED lighting system using different configurations of red plus blue LEDs was designed and a prototype was fabricated aiming to provide uniform light distribution and to save energy. Theoretical results are used for deciding the appropriate distance between LEDs. These theoretical results are obtained by using simple mathematical equations and formulae in programming. The prototype LED panel is designed for stage specific and crop specific lighting purposes as this comprises of a tuner to regulate the intensity. This designed panel has a simple shape and fabricated at a low cost. The LED lighting system is cost effective because of the simplicity of the material, manner of operation and assembly.

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