IMPACT OF GROW LIGHTS ON CROP PERFORMANCE UNDER SIMULATED GROWING ENVIRONMENT

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PROJECT REPORT

Submitted in partial fulfillment of the requirement for the degree of

BACHELOR OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

Department of Land & Water Resources and Conservation Engineering

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2016

DECLARATION

We hereby declare that, this project entitled "**IMPACT OF GROW LIGHTS ON CROP PERFORMANCE UNDER SIMULATED GROWING ENVIRONMENT**" is a bonafide record of project work done by us during the course of study, and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this project entitled "**IMPACT OF GROW LIGHTS ON CROP PERFORMANCE UNDER SIMULATED GROWING ENVIRONMENT**" is a record of project work done jointly by Abeena M.A., Mamatha Prabhakar., and Sibin.C.Baby., under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of another University or Society.

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ACKNOWLEDGEMENT

With endless pleasure, we wish to express our indebtedness and deep sense of gratitude to Dr.Abdul Hakkim V.M, Associate Professor, Head of the Dept. of Land and Water Resources and Conservation Engineering, K.C.A.E.T., Tavanur, for his expert guidance, untiring attention, sustained help and keen interest evinced throughout the course of this study. We extent our extreme gratitude to Dr. Hajilal M.S, Dean (Agrl. Engg.) for his support and co-operation during the course of work. We are truly thankful to Er. Priya.G.Nair, Asst. Professor, Dept. of LWRCE, Dr. Sathian K.K, Associate Professor, Dept. of LWRCE, Dr. Rema.K.P, Associate Professor, Dept. of IDE, Er. Shivaji K.P, Asst. Professor, Dept. of FPME and Er. Sajeena.S, Assistant Professor, KVK, Malappuram, for their constant support, prolific encouragement and didactic criticism, which helped us a lot to embark upon such an intimidating task. Also we express our fervent indebtedness to Mr.Jubail.E, Farm manager, A.R.S, Anakkayam for his constant encouragements, valuable suggestions and technical help we received for the successful completion of this study. We will be thankful to Mr. SreeKumaran.S, Asst. Librarian, L & I.C, K.C.A.E.T, for his timely help in collecting the literature for the documentation of this work.

Our deepest gratitude goes to our parents for their unflagging love and support and for providing us the best possible environment to complete this task in time.

Finally we bow before the Almighty’s feet for His grace, blessings and guidance in the path of success in every footsteps of our life through ramifying paths thick and thin of our efforts.

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Dedicated to the

Profession of Agricultural Engineering

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ABBREVIATIONS AND SYMBOLS

AD	Anno Domini
Agrl. Engg.	Agricultural Engineering
A R S	Agricultural Research Station
BC	Before Christ
C	Carbon
CEA	Controlled Environment Agriculture
cm	Centimeters
CO2	Carbon dioxide
° C	Degree Celsius
dB	Decibel
dS/m	DeciSiemens per meter
Dept.	Department
DLR	Dockland Light Railway
E	Evaporation
ET	Evapotranspiration
EU	European Union
eg.	Example
et al.	And others

Fig.	Figure
Ft	Feet
FPME	Farm Power Machinery and Energy
FYM	Farm Yard Manure
g	Gram (s)
g/m2	Gram (s) per square meter(s)
GWh	Giga Watt hour
GHG	Green House Gas
ha	hectare
hp	horse power
hrs	Hours
i.e.	That is
inch	inches
IDE	Irrigation and Drainage Engineering
J.	Journal
K	potassium
KAU	Kerala Agricultural University
K.C.A.E.T	Kelappaji College of Agricultural Engineering and Technology
kg(f)/cm 2	Kilogram force per centimeter square
kg/cm ^{2}	Kilogram per centimeter square

kg/ha	Kilogram per hectare
kg /m^2	Kilogram per square meter (s)
LDPE	Low Density Poly Ethylene
LLDPE	Linear Low Density Poly Ethylene
KPa	Kilo pascal
KWh/m2	Kilowatt hour per square meter
lbs	Pounds
Ltd.	Limited
LDCs	Least Developed Countries
LED	Light Emiting Diode
LWRCE	Land and Water Resources Conservation Engineering
m	Meter (s)
m2	Square meter (s)
ml	milli litre
mm	millimeter
Mg	Magnesium
N	Nitrogen
NGO	Non Governmental Organization
NTF	Nitrifying Trickling Filter
P	Phosphorus
PVC	Poly Vinyl Chloride

rpm	revolution per minute
sec	Second
ton/acre	Tone(s) per acre (s)

INTRODUCTION

CHAPTER 1

INTRODUCTION

Agriculture, the backbone of Indian economy, contributing to the overall economic growth of the country and determines the standard of life for more than 50% of the Indian population. Agriculture not only contributes to overall growth of the economy but also reduces poverty by providing employment opportunities and food security to majority of the population in the country and thus it is the most inclusive growth sectors of the Indian economy. The 12^{th} Five Year Plan indicates that agricultural development is an important component of faster and more inclusive sustainable growth approach.

Light, water and soil are the major factors concerned with a plant's growth. For all biological processes in a plant these factors are essential. Availability of water and the area of land for cultivation are decreasing day by day. To obtain maximum yield with minimum use of resources many modern agricultural techniques have been introduced, which gives better results than traditional methods.

Water is crucial for all living organisms and the most important use of water in agriculture is for irrigation and it consumes up to 90% of water used for agriculture in some developing countries and significant proportions in more economically developed countries (United States, 30% of freshwater usage is for irrigation). Water helps in transporting important nutrients and dissolved sugar through the plant. Nutrients are drawn from the soil and used by the plant. Without enough water in the cells, the plants droop, hence water helps for healthy crop stand and also helps the plant to maintain the proper temperature by water evaporation.

Fifty years ago, the common perception was that water is an infinite resource when there was less than half of the current population in the planet. People were not as wealthy as today, consumed fewer calories and ate less meat, so less water was needed to produce their food. They required one third volume of water we presently take from rivers. Today, competition for the fixed amount of water resources is much more intense. This is because of the reason that now there are nearly seven billion people living in the planet, their consumption of water-thirsty meat and vegetables is rising and increased competition for water from industry, urbanization and biofuel crops. In future, even more water will be needed to produce food because the Earth's population forecast is nine billion by 2050.

Soil, as an anchor for plant roots and as a water holding tank for needed moisture, provides a hospitable place for a plant to take root. Some of the soil properties affecting plant growth include: soil texture (coarse or fine), aggregate size, porosity, aeration (permeability) water holding capacity and drainability. An important function of soil is to store and supply nutrients to plants. The ability to perform this function is referred to as soil fertility. Clay and organic matter (OM) content of a soil directly influence its fertility. Greater clay and OM content will generally lead to greater soil fertility.

Light is something that sustains all life on this planet, as all things need energy to grow. We get energy from the food that we eat and plants get energy from light through a process called photosynthesis. This is how light affects the growth of a plant.

Without light, a plant would not be able to produce the energy it needed for the growth. Natural daylight has a high colour temperature (approximately 5000-5800 K). Visible light colour varies according to the weather and the angle of the Sun, and specific quantities of light (measured in lumens) stimulate photosynthesis. Distance from the sun has little effect on seasonal changes in the quality and quantity of light and the resulting plant behaviour during those seasons. The axis of the Earth is not perpendicular to the plane of its orbit around the sun. During half of the year the North Pole is tilted towards sun so that the northern hemisphere gets nearly direct sunlight and the southern hemisphere gets oblique sunlight that must travel more through atmosphere before it reaches the earth's surface. In the other half of the year, this is reversed. The colour spectrum of light that the sun emits does change not only the quantity (more during the summer and less in winter) but also the quality of overall light reaching the earth's surface.

Different stages of plant growth require different spectra. The initial vegetative stage requires a blue spectrum of light, whereas the later "flowering" stage is usually promoted with red–orange spectra. The ability of a plant to absorb light varies with species and environment, however, the general measurement for the light quality as it affects plants is the Photosynthetically Active Radiation (PAR). This measures the useful light energy received by the plant, and the spectral measurements favours the blue and red portions of the light while ignoring the green and yellow portions, which plants generally do not benefit from.

Light has three principal characteristics that affect plant growth: quantity, quality and duration. Light quantity refers to the intensity or concentration of sunlight and varies with the season of the year. Light quality refers to the color or wavelength reaching the plant surface. Red and blue light have the greatest effect on plant growth. Green light is least effective to plants as most plants reflect green light and absorb very little. It is this reflected light that makes them appear green. Blue light is primarily responsible for vegetative growth or leaf growth. Red light when combined with blue light encourages flowering in plants. Light duration or photoperiod refers to the amount of time that a plant is exposed to sunlight.

One of the major problems facing agriculture is the loss of agricultural land, because as more land is lost, it will become more difficult to produce the amount of food needed to feed the growing human population. Worldwide, around three million hectares of agricultural land are lost each year because the soil degrades and becomes unusable due to erosion, which is when soil components move from one location to another by wind or water. An additional four million hectares are lost each year when agricultural land is converted and used for highways, housing, factories and other urban needs. In the United States, around 140 million hectares of agricultural land has been lost in the last 30 years as a result of soil degradation and conversion for urban use.

Vertical farming is the advanced level of agriculture technology which has to be practiced when there is unavailability of land and other requirements for the perfect structure of farming mode. It is very useful for indoor cultivation. Vertical farming can be defined generally as cultivation of plants and other life forms by artificially stacking them vertically above each other. The concept of vertical farming helps in the efficient utilization of land and water resources. In this system crops can be protected under the roof so plants or crops cannot be affected by rain. Less amount of water is needed for vertical farming and this method requires less manpower than field work.

This vertical farming technology either uses direct sunlight or artificial light. A grow light or plant light is an artificial light source generally an electric light designed to stimulate plant growth by emitting an electromagnetic spectrum appropriate for photosynthesis. Grow lights are used in applications where there is either no naturally occurring sunlight or where supplemental light is required. Outdoor conditions are mimicked with varying colour, temperature and spectral outputs from the grow lights as well as varying intensity of lamps. Depending on the type of plant being cultivated, the stage of cultivation (eg. the germination/vegetation phase or flowering phase/fruiting phase) and the photoperiod required by the plants, specific range of spectrum, luminous efficiency and colour lamps are desirable for use with specific plants and time periods. The initial vegetative phase requires a blue spectrum of light and later flowering stage requires red-orange spectra. With a set of grow lights, we can grow many plants indoors, including houseplants, orchids and some fruit and vegetable crops. Grow lights are ideal for seed starting because they help ensure stocky, green seedlings.

LED grow lights are the newest lighting option for plants. They are most efficient and coolest running grow lights available. LED allow production of bright and long lasting grow lights that emit wavelength of light corresponding to the absorption peaks of a plant’s typical photochemical process. Compared to the other types of grow lights LED’s for indoor plants are attractive because they do not require ballasts and produce considerably less heat than the incandescent light. Energy is less utilized in the vertical farming system where LED lights (a grow light) are used instead of direct sunlight.

There are multiple absorption peaks for chlorophyll and carotenoids and LED grow lights may use one or more LED modules optimize the blue red energy produced by LED to closely match the plant requirements for optimum growth.3watt and 5 watt LED’s are now commonly used in LED grow lights. LED can be lighted by using a battery which is charged with solar energy by means of a solar panel. Thus more number of plants can be produced with same amount of sunlight when compared to direct land area receiving sunlight and being a renewable source it reduces the dependency on fastly depleting conventional energy sources.

Before LED technology, lighting research was based on conventional light bulbs that emit a wide range of wavelengths, which makes the appearance of white light. The assumption was that plants needed that wide range of wavelengths in order to thrive, just as the sun provides for outdoor plants. Research shows that plants primarily absorb light from more narrow areas of light from much more narrow areas of the light spectrum-blue and red regions specifically. Chlorophyll-the plant structure in which photosynthesis occurs absorbs peak wavelengths around 450nm and 660nm (blue and red respectively).The relationship between specific wavelengths and plant physiology/morphology showed the way for LEDs to become viable option as a sole source of lighting for plant growth.

A spectrum rich in red light relative to far-red light can suppress elongation growth, making many plants shorter and a spectrum relatively rich in far-red light promotes extension growth, making plants taller. Flowering responses are complicated, and researches are being conducted to determine how different light qualities influence flowering of day-length-sensitive species.

Daily use of grow lights for plants depends on the type of plantings. Foliage plants need about 16 hours of light per day while flowering plants require somewhat less, in the 12-14 hours range. For either type, the LED designs are very energy efficient compared with traditional indoor garden lights using fluorescent or incandescent lamps and LEDs produce less heat when compared with other types of lighting. Giving plants only the light they need is important when considering energy usage. It is inefficient (and costly) to consume energy to generate light that is useless to plants. Light energy is delivered exactly where it is needed, that is at plant canopy. Uniform light coverage across the canopy leads to even and consistent harvests throughout time.

Today, food production sector is becoming more challenging. Water scarcity has a huge impact on food production. Without water people do not have a means of watering their crops and therefore, to provide food for the fast growing population. Agriculture, which accounts for about 70% of global water withdrawals, is constantly competing with domestic, industrial and environmental uses for a scarce water supply. In attempts to fix this ever growing problem, many have tried to form more effective methods of water management.

Drip irrigation, also known as trickle irrigation, is an irrigation method that saves water and fertilizer by allowing water to drip slowly, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing and emitters. Modern drip irrigation has arguably become the world's most valued innovation in agriculture since the invention of the impact sprinkler in the 1930s, which offered the first practical alternative to surface irrigation. Drip irrigation may also use devices called micro-spray heads, which spray water in a small area, instead of dripping emitters. These are generally used on tree and vine crops with wider root zones. Subsurface drip irrigation (SDI) uses permanently or temporarily buried dripper line or drip tape located at or below the plant roots. It is becoming popular for row crop irrigation, especially in areas where water supplies are limited or recycled water is used for irrigation.

Components used in drip irrigation (listed in order from water source) include;

- Pump or pressurized water source
- Water filter(s) or filtration systems
- Fertigation systems (Venturi injector, fertilizer pump or tank) and chemigation equipment (optional)
- Backwash controller (Backflow prevention device)
- Pressure control valve (pressure regulator)

- Main line (larger diameter pipe and pipe fittings)
- Hand-operated, electronic, or hydraulic control valves and safety valves
- Smaller diameter poly tube (often referred to as "laterals")
- Poly fittings and accessories (to make connections)
- Emitting devices at plants (emitter or dripper, micro spray head, inline dripper or inline drip tube)

Properly designed, installed and managed, drip irrigation may help to achieve water conservation by reducing evaporation and deep drainage when compared to other types of irrigation such as flood or overhead sprinklers since water can be more precisely applied to the plant root zone. In addition, drip can eliminate many diseases that are spread through water contact with the foliage. Finally, in regions where water supplies are severely limited, there may be no actual water savings, but rather simply an increase in production while using the same amount of water as before. In vertical farming system plants can be grown in troughs or containers of lightweight, inert sheet materials that can be reused for years. Small tubing on the surface rips nutrient-laden water precisely at the base of each stem. This eliminates the need for vast quantities of water used in traditional irrigation.

Instead of soil, coco peat or inorganic media such as vermiculite, perlite, rock wool etc. can be used with an external supply of nutrients. Coco peat is made from coconut husks and has absolutely no nutrition in it, but has excellent water retention capacity. Benefits of coco peat are it is fibrous, spongy and helps to retain moisture for a much longer time because of the water absorptive and retentive nature of the fibre, which means that we require less water and need to irrigate plants after far long intervals. Being lighter in weight all these media will bring down the overall weight of the potted mix when compared to the use of soil. Besides the weight reduction, inorganic media also possess a fair amount of water holding capacity along with good drainability. Thus it mitigates the problems associated with both water scarcity as well as excess water. So the use of soilless media in agriculture helps to achieve the twin goals of soil and water conservation.

If we are developing a vertical structure suitable for indoor farming which contains lighting system, drip system for irrigation etc. under controlled environment, it will be beneficial for people living in flats and in urban areas. This type of set up can be established also in offices, industries, railway stations, schools etc. Thus available space can be effectively utilized and demand of food supply can be met from within the cities.

The main objective of the present study is to monitor the impact of grow lights on crop performance under simulated growing environment. The specific objectives are:

- To study the impact of grow light in vertical farming in a dark and/or shaded environment with artificial lighting using LED strips.
- To study the impact of grow light on incremental area available for cultivation in comparison with the direct area receiving sunlight.
- To develop a simple structure, which can give maximum yield with minimum inputs.

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

Due to fast growth of urbanization, agricultural lands are being converted to industrial zones and the land available for agricultural activities is being decreased at a faster rate. The agricultural lands are heavily occupied by industries and business centres during the past few decades. For survival of mankind agriculture is necessary, but there is lack of interest in agricultural activities in the minds of people. To overcome these difficulties and reduce land exploitation vertical farm concept has been raised (Bailey, 1915). The underlying strategies for moving towards sustainable farming systems are conservation of soil, water and energy resources to maximize food production. This goes back to the functioning of ecosystems, the dynamics of interactions between a community and its non-living environment. Agro ecology is an approach in agricultural development which draws modern ecological knowledge and methods and it is defined as the application of ecological concepts and principles to the design and management of sustainable agro ecosystems (Gliessman, 2000). Vertical farming technology confirms crop production all year-round irrespective of the environmental conditions. According to "The encyclopedia of earth, 2010, 30 storey high building with a basal area of 5 acres (2.02 ha) has the potential of producing crop yield equivalent to 2,400 acres (971.2 ha) of traditional horizontal farming. Expressed in ratio, this means that 1 high-rise farm is equal to 480 traditional horizontal farms. The vertical farming technology includes hydroponics and aeroponics which consumes very less amount of water than utilized in conventional agriculture. Vertical farming will reduce the dependency on land resources and help in re-growth of forests. Further, due to less use of equipments, it will lead to decrease in CO_2 emission, thus help in conservation of the environment (Garg and Balodi, 2014). There are many assets in the vertical farming technology, where one of the most beneficial thing is reliable cropping, there is no any seasonal cropping is needed as every process of the system are done with the interior process so the crops can harvest at any season in interior farming. Also by applying this technique there will not be any crop loss and other benefit of interior framing are stated as no bugs can infect crops and climatic changes cannot affect the crops. Energy is less utilized in the vertical farming system where LED lights are used instead of the sunlight for the growing of crops better than under the sunlight (Jegadeesh, 2014).

Vertical farming is a technique, which is the combination of skyscraper and greenhouse effect together to form the advanced level of agricultural practices and vertical farming technology is used to cultivate crops through artificial sunlight or through the direct process (Jegadeesh et al., 2014). As the vertical farming system comprises of various methodologies, it is the eco-friendly process, as we are able to cultivate any kind of crops at any duration process, multiple-crops can be cultivated in this process and if a heavy rain comes in case of normal farming, it may damage all the crops, but in this system the crops are protected under the buildings so the plant or crops cannot be affected through rain (Veerapandi, 2014).

2.1 Photosynthesis and photoperiodism

Oxygenic photosynthesis, the fundamental process of conversion of sunlight into chemical energy, sustains life on earth. The first step in this process, the light-driven charge separation, is conducted by photosystems (PS) I and II, two large multimeric chlorophyll binding protein complexes embedded in the thylakoid membranes of cyanobacteria, algae and higher plants. Carbohydrates, such as sugar glucose ($C_6H_{12}O_6$) and oxygen (O_2), are the main products of the photosynthesis process. These are synthesized from carbon dioxide (CO_2) and water (H_2O) using the photons' energy harnessed by using specialized photoreceptors such as chlorophylls and converted into chemical energy. Through photosynthesis, the radiant energy is also used as the primary source of chemical energy, which is important for the growth and development of plants. Naturally, the stoichiometry of the equation is also dependent on the quantity (i.e. number of photons) and quality (i.e. photons' energy) of the radiant energy and, consequently, also of the produced biomass of the plants. Photoperiodism refers to the ability that plants have to sense and measure the periodicity of radiation, phototropism to the growth movement of the plant towards and away from the radiation, and photo morphogenesis to the change in form in response to the quality and quantity of radiation (Hart, 1998)

2.2 Effect of sun light on plant growth

The quantity of light falling on a surface at a given moment, usually referred to as “light intensity,” is formally defined in terms of either energy per unit area (= irradiance) or quanta per unit area (= photon flux: Kitaya et.al,1998). Korczynski et.al (2002) reported that some elements of the variation in irradiance are predictable. For example variation with time of day, season and latitude are all functions of the elevation of the sun in the sky (the higher the solar elevation, the higher the irradiance). As a result, irradiance reaches a maximum near the equator at mid-day and, at mid-high latitudes in mid-summer. Superimposed on these systematic geographical and seasonal variations in irradiance are variations due to factors like cloud cover, aspect on a sloping site, or shade from nearby structures or plant canopies. Some of these factors affect all wavelengths of light more or less equally, others are much more wavelength specific. Many biological responses to light can be described as simple functions of irradiance, the rate of photosynthesis in plants is a typical example (Cladwell et.al, 2003)

Dielen et.al (2004) stated that although photosynthesis is a function of irradiance, growth is determined by the sum of photosynthetic carbon fixation over time which is, in turn, a function of the amount of light received by the plant over that period. Thus, growth and yield, and many other long-term effects of light, are best described by the accumulated dose of photosynthetic radiation, for example by daily light integral.

2.2.1 Supplemental lighting for plant growth

Light is a primary factor influencing growth and development of plants and to a considerable degree, it determines the appearance of plants, their growth rate as well as the duration of reaching individual development stages. Light quality influences the growth and morphogenesis of many plants grown in a closed system at artificial sources of light. Presently, many types of garden crops are cultivated under fluorescent lamps, HPS and LEDs, which are becoming especially popular for vegetable crops (Liu et al.2011).

2.2.2 Fluorescent lamps as grow lights

Fluorescent lamps are more commonly utilized in plant-growth applications than incandescent lamps. The electro-optical energy conversion is more efficient in comparison to incandescent lamps. Tubular type fluorescent lamps can achieve electrical efficiency values from typically around 20% to 30%, where more than 90% of the emitted photons are inside the PAR region with typical life times of around 12000 hours (Murdoch, 1985).

Barta et al. (1992) reported that cool-white fluorescent lamps also emit in red and infrared regions and therefore phytochrome might have been activated in a way that could justify an interacting effect on elongation. It was also concluded that a certain amount of elongation is necessary. Therefore, 15 to 30 μmol m-2 s-1 of a photosynthetic photon flux density with a 12-h photoperiod due to blue radiation would be acceptable for lettuce growth. The findings of earlier studies were also confirmed in the sense that lettuce seedlings respond to a specific number of blue photons rather than to a ratio between the blue photosynthetic photon flux and the total photosynthetic photon flux. Besides their reasonable energy efficiency and lifetime, another advantage of fluorescent lamps in plant growth is the amount of blue radiation emitted. This can reach more than 10% of the total photon emission inside PAR, depending on the correlated colour temperature (CCT) of the lamp. For this reason, fluorescent lamps are frequently used for total substitution of natural daylight radiation in close growth rooms and chambers. The blue radiation emitted is indispensable to achieve a balanced morphology of most crop plants through the mediation of the crypto chrome family of photoreceptors (Goins et al, 1997).

2.2.3 LEDs as supplemental light

Light-emitting diodes (LEDs) are a promising electric light source for space based plant growth chambers and bio-regenerative advanced life support because of their small mass and volume, solid state construction, safety, and longevity. Bula et al. (1991) at the University of Wisconsin first suggested using LEDs to grow plants and reported that growth of lettuce plants under red LEDs supplemented with blue fluorescent (BF) lamps was equivalent to that under cool-white fluorescent (CWF) plus incandescent lamps. At the time of that study, blue LEDs were not yet widely available, so BF lamps were used as an alternative. Subsequent testing by that group showed that hypocotyls and cotyledons of lettuce seedlings under red (660 nm) LEDs became elongated, but that effect could be prevented by adding at least 15 mmol/m²/s of blue light (Hoenecke et al., 1992).

These findings inspired continued development of LED lighting systems for small plant growth chambers that flew several times aboard NASA's Space Shuttle. In the photosynthetically active radiation range, the electrical efficiency of gallium aluminium arsenide (GaAlAs) red LEDs has been reported to be greater than that of fluorescent lamps and comparable to high-pressure sodium lamps (Barta et al., 1992). Kendrick and Kronenberg (1994) reported that red LEDs emit a narrow spectrum of light (660 nm with 25 nm bandwidth at half peak height) that is close to the maximum absorbance for both chlorophyll and phytochromes. Although red LEDs have great potential for use as a light source to drive photosynthesis, plants are adapted to utilize a wide-spectrum of light to control photomorphogenic responses. LEDs were used to grow wheat (*Triticum aestivum* L.) and *Brassica rapa* L. seedlings (Morrow et al., 1995), potato (*Solanum tuberosum* L.) leaf cuttings (Croxdale et al., 1997), *Arabidopsis thaliana* (Stankovic et al., 2002), and soybeans (*Glycinemax* L.) (Merr Zhou, 2005).

Light-emitting diodes (LEDs) have a variety of advantages over traditional forms of horticultural lighting. Their small size, durability, long lifetime, cool emitting temperature, and the option to select specific wavelengths for a targeted plant response make LEDs more suitable for plant-based uses than many other light sources. These advantages, coupled with new developments in wavelength availability, light output and energy conversion efficiency, place us on the brink of a revolution in the field of horticultural lighting (Massa et al., 2008).

The high capital cost is still an important aspect delaying the uptake of LED technology in horticultural lighting. Despite this, the technical development of LEDs is expected to reduce capital and operating costs in the future (Massa et al. 2008, Morrow 2008, Yeh and Chung 2009, Vanninen et al. 2010). Major advantage of LEDs over all other lamp types for plant lighting is that the technology is evolving in electrical- use efficiency at a rapid pace. For example blue LEDs that were only 11% efficient in 2006 were reported to be 49% efficient converting electrical energy to photon energy in 2011 (Mitchell et al. 2012). LED efficiency in general, is projected to raise considerably, both as electrical efficiency and photon flux efficacy over coming decade. It is predicted that the photosynthetic efficacy of red LEDs will be double of the HPS lamp by the year 2020 (Pinho et al.2012).

By using proper lightings to the plants we can stimulate its growth this is termed as artificial photosynthesis. This is what we see in botanical gardens. So above the crops we provide lights focusing the crops. Now-a-days, LED bulbs are more energy conserving and it is also suitable for artificial photosynthesis process (Balachandar C, 2014).

2.2.4 Use of solar energy in plant lighting systems

2.2.4.1 Solar photovoltaics

The most abundant fuel source in the realm of renewable energy is the sun. Solar panels produce electricity through individual photovoltaic cells connected in series. This form of energy collection is viable in regions of the world where the sun is plentiful and can be used in isolated regions or on houses to supplement the rising cost of electricity from a power grid. To convert the sun’s energy, the cells capture photons to create free electrons that flow across the cells to produce usable current (Penick et.al, 1998). The efficiency of a solar panel is determined by the semiconductor material that the cells are made from as well as the process used to construct the cells. Solar panels come in three types: amorphous, mono-crystalline and polycrystalline (Messenger and Ventre, 2000). The more efficient the material from which the panel is constructed, the greater will be its cost. To maximize results, there are many features that can be used to control the output of the photovoltaic panels.

2.2.4.2 Maximum Power Point Tracker (MPPT)

MPPT is the focal point of the system; connecting the panel, battery bank and the load. To prevent overcharging, an MPPT maximized the amount of energy that reached the batteries. MPPT also called as a solar charge controller uses a pulse width modulation to deliver a constant charging voltage to the batteries and thus produces a stable charge current. Additionally, the controller monitors temperature and makes the adjustments to handle the electrochemical properties of the battery to limit the amount of heat gained during charging. Maintaining a constant power output requires a power converter to control the voltage and current to match a specified range that maximizes output efficiency and prevents overcharging the capacitor (Appelbaum , 1989). Yuvarajan (2003), reported that the use of a MPPT increases efficiency and lowers the cost and amount of equipment needed for the system. Compared with a much higher wattage panel that produces the same amount of energy, a smaller panel with an MPPT will equal the average power produced. The benefits of the MPPT are in the savings realized by using the smaller panel and the increased efficiency of all systems connected to it. The output voltage was held constant, while the output current was dependent on the light intensity and temperature of the panel.

2.3 Growing medium

The term ‘growing medium’ is amongst others used to describe the material used in a container to grow a plant. Worldwide, a high percentage of the hydroponic industry uses inorganic growing media such as rock wool, sand, perlite, vermiculite, pumice, clays, expanded polystyrene, urea formaldehydes and others (Sawan et al., 1999; Bohme et al., 2001; San Bautista et al., 2005; Bohme et al., 2008), while only about 12% uses organic growing media (Donnan, 1998). The terms ‘substrate’

(Schroeder, Sell, 2009; Vaughn et al., 2011) and ‘rooting medium’ (Blok, Verhagen, 2009) are also used as synonyms. Growing media have three main functions:

1) Provide aeration and water

2) Allow for maximum root growth, and

3) Physically support the plant.

Growing media should have large particles with adequate pore spaces between the particles (Bilderback et al., 2005). In the United Kingdom some people still use the term ‘compost’ in the same context. However, compost is technically the product of a composting operation (e.g., a compost heap at the bottom of the garden) and therefore could be misleading. On the other hand, composted materials have routinely been used as a growing medium or components of growing media (Schroeder, Sell, 2009; Nair et al., 2011). Soilless media are materials, other than soils *in situ*, in which plants are grown. These can include organic materials such as peat, compost, tree bark, coconut (*Cocos nucifera* L.) coir, poultry feathers, or inorganic materials such as clay, perlite, vermiculite, and mineral wool (Grunert et al., 2008; Vaughn et al., 2011) or mixes such as peat and perlite; coir and clay, peat and compost (Nair et al., 2011).

2.3.1 Soilless culture

Soilless culture is the modern cultivation system of plants that use either inert organic or inorganic substrate through nutrient solution nourishment. Possibly it is the most intensive culture system utilizing all the resources efficiently for maximizing yield of crops and the most intense form of agricultural enterprises for commercial production of greenhouse vegetables (Jensen et.al, 1999; Dorais et al., 2001; and Grillen et al., 2001). Several studies suggested soilless culture in the greenhouse as an alternative to traditional field production for high-value vegetable crops (Blank, 1999; Schroder, 1999; Cantilffe et al.2001; and Paradossi et al, 2001). This protected cultivation system can control the growing environment through management of weather factors, amount and composition of nutrient solution and also the growing medium. Therefore, quality of horticultural crops grown through soilless culture improves significantly compared to conventional soil culture (Massantini et al, 1988; Gauthier et al, 1995).This artificial growing system provides plants with mechanical support, water and mineral nutrient for higher growth and development. Bilderback (2005) reported that various modification of pure solution culture has been taken place over time throughout the world. Primarily, gravel or sand was used in soilless culture system to provide plant support and retain mineral nutrient and water. Afterward, several substrates have been evolved due to their unique properties for holding moisture, aeration, leaching or capillary action, and reuse potentiality. Soilless growing media are easier to handle and it may provide better growing environment (in terms of one or more aspects of plant growth) compared to soil culture Mastouri et al, 2005). Organic substrates includes sawdust, coco peat, peat moss, woodchips, fleece, marc, bark etc. whereas, inorganic substrate of natural origin are perlite, vermiculite, zeolite, gravel, rockwool, sand, glass wool, pumice, sepiolite, expanded clay, volcanic tuff and synthetically produced substrates include hydrogel, foam mates (polyurethane), oasis (plastic foam) etc. (Dorais et al, 2007; Mahamud et al, 2007; Ehert et al, 2009 and Olle et al, 2012). Asao (2012) stated that, over the years, hydroponics has been used sporadically throughout the world as a commercial means of growing both food and ornamental plants. Now at days, it has also been used as the standard methodology for plant biological researches in different disciplines.

2.3.1 Mineral soil versus growing medium

Most greenhouse vegetable production systems use either hydroponic systems with rock wool or perlite or various organic soilless substrates. Alan et al. (1994) grew tomato plants in soil, perlite, peat, sand, pumice and different combinations of them. Their results showed that the highest total as well as marketable yield was produced with a mixture of 80% pumice + 10% perlite + 10% peat medium, providing about 30% more product in comparison to the soil.

In cucumber, the total yield was higher for plants grown in nutrient film technique (NFT) compared to sandy soil (Al-Harbi et al., 1996). Lettuce plants harvested from perlite or pumice culture had a lower dry matter, chlorophyll, Mg, Fe and Mn content and a higher titratable acidity as well as total N, P, and K content, in comparison with the plants harvested from the soil culture (Siomos et al., 2001). In addition to yield, the growing medium has shown effects on other plant parameters. Dry matter content was highest in lettuce grown in tea waste compost and lower in tree bark compost. Soilless growing media are easier to handle and may provide a better growing environment compared to soil. In a study comparing various growth media, showed that the head weight of lettuce was highest in plants grown in tea waste compost, lower in plants grown in tree bark compost and lowest in plants grown in soil (Bilderback et al(2005) and Mastouri et al., 2005). Moreover, crops reached maturity earlier when the plants were grown in tea waste compost or in tree bark compost compared to the soil. According to Gruda (2009), a number of authors have reported improved uniformity in weight, size and texture of tomatoes grown in soilless culture systems compared to those grown on soil. A few authors reported that soil culture could increase the size of tomatoes compared to soilless culture systems (Gruda, 2009).

2.4 Drip irrigation system

Ahluwalia *et al. (*1993) observed that when compared with conventional irrigation systems, drip system yielded on an average 6 and 56 per cent higher and saved upto 57 and 37 per cent irrigation water in tomato and cauliflower crops respectively resulting in a tremendous increase in water use efficiency. They also revealed that at optimum irrigation levels, the drip method resulted in saving of water by 38 per cent with consequent increase of 60.9 per cent in water use efficiency over the surface irrigation method. The irrigation requirement of hybrid tomato crop was studied by Bafna *et al*. (1993). Irrigation requirement was found to be 67 ha.cm in surface method and 32 ha.cm in drip method, thereby effecting a saving of 53 per cent of irrigation water by using drip system. Bankar and Pampattiwar, (1995) recorded considerable increase in chilli yield with drip over surface irrigation. Drip irrigation offered maximum water use efficiency, increase in yield, better quality fruits and highest net profit in watermelon (Benke, 1995). As reported by Chandio and Yaseen, (1995) higher water use efficiency was obtained under drip irrigation (1.21 kg/ha.m3) than under furrow irrigation (0.44 kg/ha.m3) in chillies.

2.5 Experimental crops

2.5.1 Coriander

Coriander (*Coriandrum sativum* L.) is an aromatic herb, cultivated as a summer or a winter annual crop, depending on the climatic conditions. The traditional uses of coriander plants, based on the primary products (fruits and the green herb) are twofold: medicinal and culinary. The fruits are considered carminative, diuretic, tonic, stomachic, antibilious, refrigerant and aphrodisiac. They are also used as a condiment in the preparation of sausages, seasonings and cookies, and as flavouring for alcoholic beverages (Diederichsen, 1996). Coriander plants grow poorly during the summer heat, and will bolt because cilantro is a long day plant (Gibson et al., 2000). The other primary product, the fresh green herb of coriander, also known as cilantro, has a specific flavour, completely different from that of the fruits. The characteristic smell of the green plant is due to the aldehydic content of the essential oil (Deng et al., 2003). Coriander also possess antibacterial (Lo Cantore et al., 2004) and antioxidant activity (Chericoni et al., 2005).

2.5.2 Amaranthus

The main vegetable type of amaranth, *Amaranthus tricolor* L., seems to have originated in South or Southeast Asia (Grubben et.al, 1981) and then spread through the tropics and the temperate zone (Martin et.al, 1979). The two main types of amaranth grown as leafy vegetables are loosely termed red amaranth and green amaranth. Red amaranth grows well in hot and humid weather. However, during winter, red amaranth growth and development is slow, compared with summer and rainy season (Bose et.al, 1993). The fresh tender leaves and stem of red amaranth are delicious when are cooked by boiling and mixing with condiments. The leaves and tender stems of red amaranth are rich in protein, minerals, vitamin A and C (Wadud et.al, 2002). Khandaker et.al,(2010) reported that, the most important agronomic considerations for red ameranthus growers to optimize yield and quality are to select optimum air temperature and sunlight intensity. The correlation between plant height and mean growing period air temperature and sunlight intensity was highly significant, which confirms air temperature and sunlight variability is a major factor influencing plant growth. Amount and effects of air temperature and sunlight intensity during plant growing period, significantly affected biomass yield, leaf colour and betacyanin accumulations, (Khandaker et.al, 2010).

Based on the review of the work done in the past, a study has been conducted to monitor the impact of grow lights on plant growth in vertical farming. A grow light based vertical farming structure has been developed and it is used for the study.

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

In the present study an attempt was made to develop a vertical farming structure with artificial lighting using grow lights, suitable for cultivation in shaded areas. Material used and methodology adopted for the study is briefly discussed in this chapter.

3.1 Location of the study

The experiment was conducted inside the Precision Farming Development Centre (PFDC) building of KCAET, Tavanur, in Malappuram district, Kerala. The place is situated at 10˚52' 30" North latitude and 76˚East longitude. The total area of KCAET campus is 40.99 ha, out of which total cropped area are 29.65 ha. Agro climatically, the area falls within the border line of Northern zone and Central Zone of Kerala. Major part of the rainfall in this region is obtained from South West monsoon. The area is having a relative humidity of about 62%. The mean maximum temperature of the area is about 42.1 ˚C and mean minimum temperature of the area is about 22˚C. A room of 6x6x6 m dimension, having an average lux of about 500-1500 was used for the study. The whole structure was installed at one corner of the room.

3.2 Experimental set up

3.2.1 Vertical structure

Vertical farming can be defined generally as cultivation of plants by artificially stacking them vertically above each other. The vertical structure for the project was of four arrays fabricated with 30 mm MS angle and mild steel sheet of 1.5 mm thickness. Each array has an area of 85 x 125 cm. One array lies at a height of 65cm above the other. Three arrays (total area of 3.19 m^2) were used for the cultivation and top layer was constructed with an aim to install a small water tank to support irrigation. Total height of the setup was 2.4 m.

Each array was made to plant 21 plants in such a way that plant to plant distance was 20 cm and plant to side of the array was 10 cm. Each array except top one had 21 holes having a diameter of 1.25 inch. The holes can be used to support grow bags. The setup was placed in the shaded room to simulate the conditions inside a building, so that the plants will not get direct sunlight essential for its growth and metabolic activities.

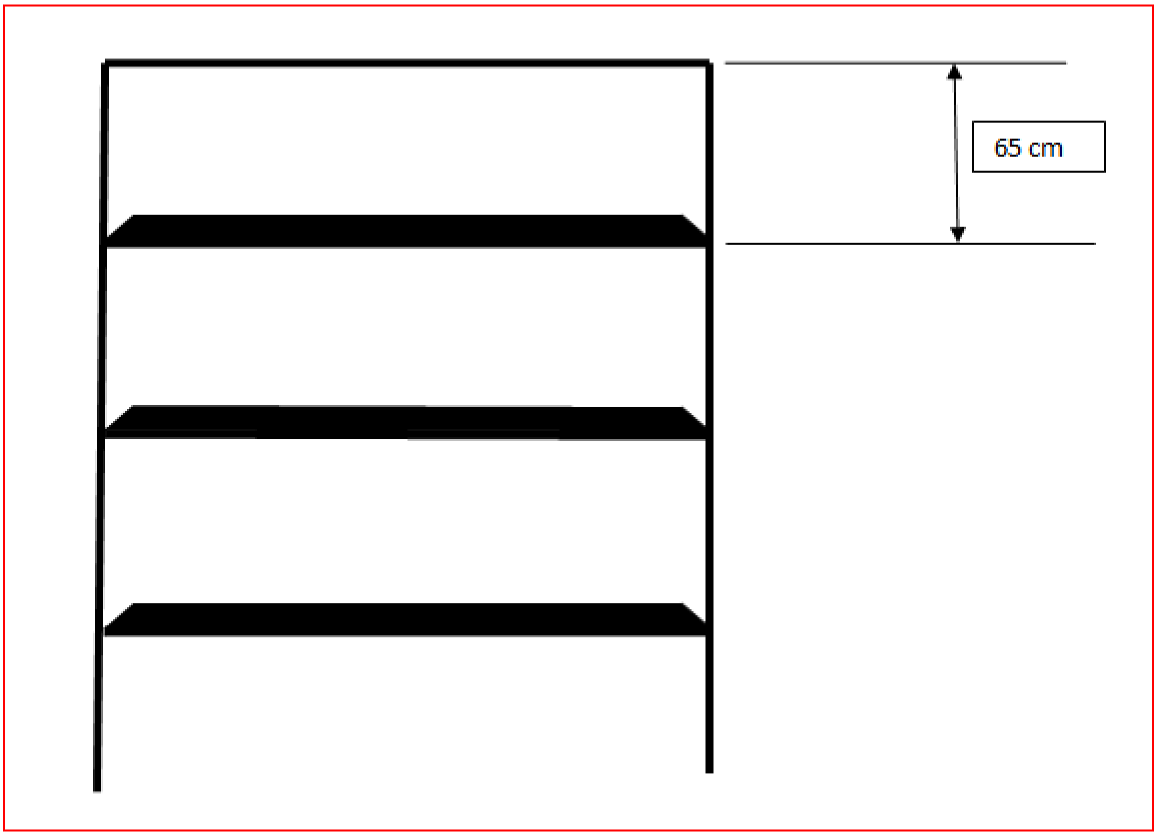

Fig. 3.1 Elevation of vertical farming structure

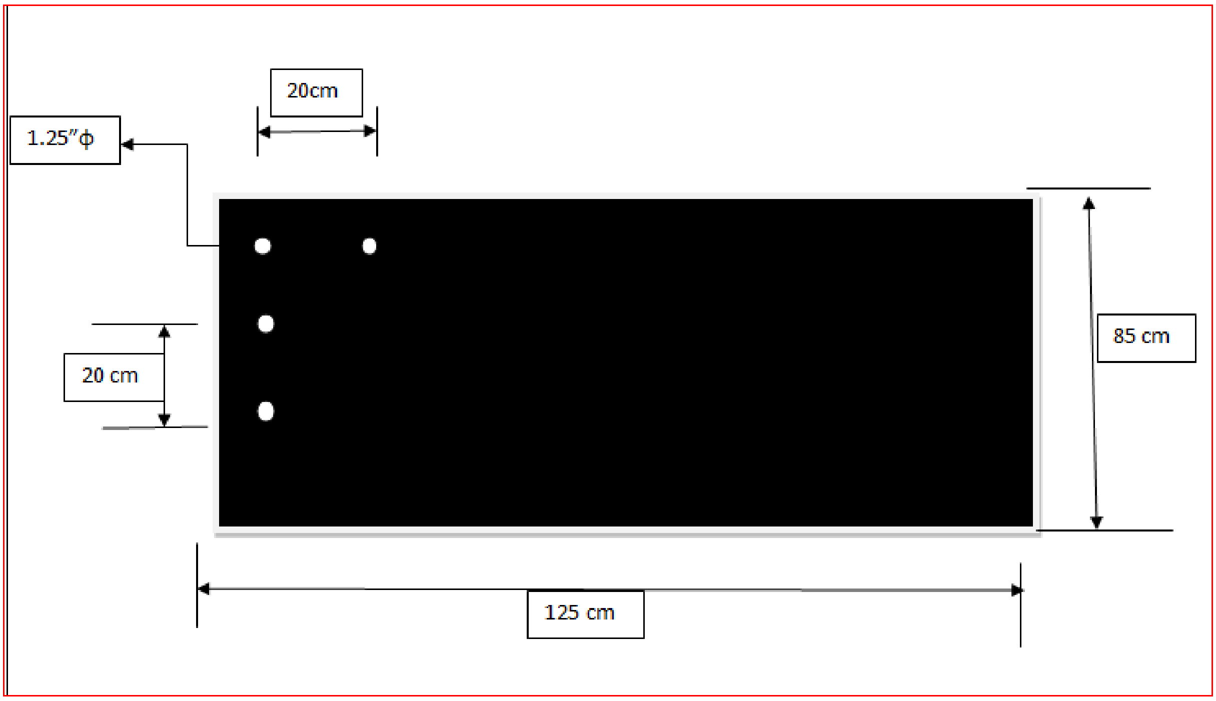

Fig. 3.2 Plan of vertical farming structure

3.2.2 Lighting System

Artificial lighting was given by using grow lights such as LED and fluorescent grow lights. A grow light or plant light is an artificial light source, generally an electric light, designed to stimulate plant growth by emitting an electromagnetic spectrum appropriate for photosynthesis.

3.2.2.1 LED strip

Red-Green-Blue (RGB) strip having 5 m length was used for the study in order to use any colour combinations by supplying power to the terminals. Each 1 m strip contains 40 lights. LED grow strip for plant production is coated with water resistant silicon cover. High flexibility, small size and low thermal emission makes it ideal for use in many horticultural applications where lighting can be precisely directed for optimal plant growth.

Each cultivating array was supplied with 5 m LED strip fitted at the lower portion of preceding array (at a height of 65 cm) so that light reaches on each plant uniformly. Top layer LED was connected such as to get blue light only, middle layer was supplied with red LED and bottom layer LED was connected to get a combination of red and blue LED.

LEDs allow production of bright and long-lasting grow lights that emit only the wavelengths of light corresponding to the absorption peaks of a plant's typical photochemical processes. Compared to other types of grow lights, LEDs for indoor plants are attractive because they do not require ballasts and produce considerably less heat than incandescent lights. LEDs are usually with a temperature of 45-60 degrees Celsius. Plants under LEDs transpire less as a result of the reduction in heat and thus the time between watering cycles is longer.

3.2.2.2 Fluorescent light

In addition to LED, lighting system is supplemented with white fluorescent lamp of 9W, to provide the sufficient luminance for plants. Total three lamps were used, such that each array was provided with one lamp. Since the use of LED increases the total operating cost of the system fluorescent light may also be an appropriate choice. The disadvantage of this is that it causes heating this may harm the plants.

3.2.2.3 Solar panel

In order to provide a continuous supply of light to the structure, a solar panel having the dimension of 1.5 x 0.5 m^2 producing 75-100 watts during sunshine was used. The usage of solar panel assure that the area for cultivation, in a vertical structure, by using grow lights is much more than in normal case. Solar panel also assures the energy consumption principle. Solar panel was installed at the top of the roof facing the north-south direction such that each module can collect maximum sunlight.

3.2.2.4 Battery

A 25 AH and 12V battery in order to store the charge from the solar panel is installed. This could provide an uninterrupted supply of charge to the LED lights.

Plate 3.1 Fabricated vertical structure

3.2.2.5 Maximum power point tracker

In order to control charging and discharging of the battery a solar charge controller is used, which can restrict the overcharging of the battery and also decrease the discharging of the battery during non charging conditions. The solar charge controller has 3 bed switches to control the three lights.

Plate 3.2 Solar panel

Plate 3.3 Battery

3.2.3 Micro fan

Ventilation was given to the completely closed structure by means of 2 micro fans of size 50x50x10mm having a speed of 5000 rpm, working under 9.8-14.8

VDC. The fans act as an exhaust as well as inlet. The air pressure produced is 2.53 mm H_2O. It was also operated by solar power.

3.2.3 Growing media

Soilless growing media is more suitable when indoor vertical farming is considered, since they are lighter in weight, increased water holding capacity, reduced risk of soil born pest and disease, good aeration etc. Taking above factors into account the following media were used for the study.

3.2.3.1 Vermiculite

Vermiculite is a mineral that has been superheated until it has expanded into light pebbles. It has very high water holding capacity. Also poses excellent exchange and buffering capacity. If not handled properly, vermiculite compacts and loses its ability to hold air. Vermiculite holds water and fertilizer and contains calcium and magnesium.

3.2.3.2 Perlite

Perlite is a volcanic rock that has been superheated into very lightweight expanded glass pebbles. This is a chemically inert material with a pH ranging from 6.5 to 7.5. It has high stability and not susceptible to acids and microorganisms. Perlite can hold good amount of water and air. Perlite can hold 3-4 times its weight in water, yet will not become soggy.

Plate 3.4 Maximum power point tracker

Plate 3.5 Vermiculite

Plate 3.6 Perlite

Plate 3.7 Micro fan

3.2.3.3 Coco peat

Coco peat, also known as coir or coco, is the leftover material after the fibres have been removed from the outermost shell (bolster) of the coconut. Coir is 100% natural grow and flowering medium. Coconut coir is colonized with trichoderma fungi, which protects roots and stimulates root growth. It is extremely difficult to over-water coir due to its perfect air-to-water ratio; plant roots thrive in this environment. Coir has a high cation exchange, meaning it can store unused minerals to be released to the plant as and when it requires it. Coir is available in many forms, most common is coco peat, which has the appearance and texture of soil but contains no mineral content. It can be mixed with farm yard manure which stimulates the plant growth.

Plate 3.8 Coco peat

3.2.3.4 Sand

Sand is the least expensive and most readily available material. It does not hold water very well and hence usage of sand in the potting mixture will help to drain excess water. Sand is the heaviest ingredient used in potting mixes which is good for top-heavy plants that might blow or tip over, but bad for plants that will be shipped or moved a lot.

Plate 3.9 Sand

The following combinations of media were prepared and are filled in growing containers for comparing their performance:

Table 3.1. Different combinations of rooting media used for the study

Sl. No.	Components	Ratio
1	Vermiculite+ Perlite (V+P)	2:1
2	Vermiculite+Perlite+Sand (V+P+S)	2:1:1
3	Cocopeat+Cowdung (CP+CD)	3:1

3.2.4 Irrigation system

Irrigation was done by drip method. Laterals of 12 mm size and online drippers of 2 liters per hour capacity were used. For this type of cultivation practice drip irrigation is more suitable. Plants were irrigated once in two days. Since the growing media are of with high water holding capacity and transpiration is comparatively less small quantity of water is needed.

Plate 3.10 Drip irrigation system in vertical structure

3.2.5 Selection of Crop

Two crops were selected for the study under different light conditions inside the structure. For analysis of growth under complete dark condition with only light source of LED grow light (low light intensity condition), Co-1 variety of coriander plant was selected. Coriander is an annual herb belongs to the family of Apiaceae. Coriander grows well in dry and cool weather. It performs well within a temperature range of 20 to 30^0C. Best season to grow is June to July and October to November. The optimum pH range 6 to 8 is best suited for its cultivation. Irrigation should be given immediately after transplanting and at second and third day after transplanting and thereafter every alternate day.

Crop selected for cultivation under diffused sunlight supplemented with grow lights was Kannara local variety Amaranthus. It is a most common leafy vegetable grown during summer and rainy season in India. It belongs to the family *Amaranthaceae* and one of the most resistant varieties of amaranthus. It belongs to C-4 group of plants and has efficient photosynthetic ability. Crop selection was based on characteristics such as resistance to pest, diseases and climate, plant height, root growth etc. Moreover leafy vegetables are more suitable for this kind of cultivation. A temperature range of 20 to 30^oC is required for better vegetative growth.

3.3 Methodology

A vertical structure of 85 x 125 x 65 cm dimension was fabricated and successfully installed in the room selected for experiment. Drip irrigation setup was made. A solar panel having 70 to 100 Watt capacity was installed on the top of roof. LED strips and fluorescent lighting arrangements were given. Two trials were carried out for the study.

- Study under complete dark condition with LEDs as only lighting source.
- Study under diffused sunlight condition supplemented with grow lights (both LED and fluorescent lights)

Experiments under each trial was done with the following treatments

Table 3.2 Different treatments used for the study

MEDIUM / LIGHT	V+P+S	V+P	CP+CD
BLUE	**T1**	**T2**	**T3**
RED	**T4**	**T5**	**T6**
RED+BLUE	**T7**	**T8**	**T9**

3.3.1 Under complete dark condition supplemented with grow lights

The three sides of the structure were covered with sulphate boards and the windows were completely covered with black charts so that only light source inside the structure was LED. Artificial ventilation was given to the structure by using micro fans. Seedlings were raised in pro trays and transplanted to the growing containers after 3 weeks.

Total 63 plants were transplanted such that each array contains 21 plants having plant to plant spacing of 20 cm. Drip emitters of 2 lph were used to provide irrigation to the root zone of each plant. The duration of irrigation set was 5 minutes, once two days. NPK solution made by dissolving 5 g per litre water was applied once in a weak as fertilizer. Growth of the plants were observed on 5^{th}, 10^{th} and 15^{th} days after planting and the biometric observations for each treatment were taken and tabulated for ANOVA

(**a**) (**b**)

Plate 3.11 (a) & (b) Coriander plants under dark condition supplemented with grow lights

3.3.2 Under shaded condition supplemented with grow lights

Here sulphate board covered on three sides and black papers on window glasses were removed, so that sunlight could diffuse into the room and to the structure. This condition of light was supplemented with LED and Fluorescent grow lights so that light intensity sufficient for plant growth was available.

Kannara local variety was selected for study under this condition. Amaranthus seedlings of 20 days old were transplanted from pro trays to grow bag containing three different media. Each growing array contains 9 containers with vermiculite-perlite media, 9 containers with coir peat –cow dung media and last 9 containers with vermiculite- perlite-sand media. Drip emitters of 2 lph were placed at the root zone of the plant and irrigation was given once in two days. A total number of 27 plants were used for this study. Biometric observation of plants in each array under blue light, red light and red-blue combination and three different media were taken and tabulated for ANOVA.

Plate 3.12 Amaranthus under shaded condition supplemented with grow lights

3.3 Determination of light intensity inside the room

Light intensity is an important parameter, since main aim of this project is to study the impact of artificial grow light on plants. Light intensity in lux, inside the room was measured for two studies using a high range lux meter. Measurement of light intensity was made thrice in a weak during morning, noon and evening and average lux was obtained.

3.4 Biometric observations

For analyzing the growth of the plants under different treatments, three plants were selected randomly from each array. Biometric observations such as plant height and number of leaves were made after every 5 days for coriander and 10 days for amaranthus. The overall growth for coriander and amaranthus were assessed over a period of 15 and 30 days respectively. The collected data were tabulated and compared separately for each trial.

The heights of the randomly selected plants were measured from the surface of the rooting media to the tip of the plant. Numbers of leaves of randomly selected plants of each array were counted after every 5 days for coriander and 10 days for amaranthus. Harvesting of coriander was done 15 days after transplanting and that of amaranthus was done 30 days after transplanting and weighed for analysing the total yield.

RESULTS AND DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

The study has been undertaken with the objectives to study the impact of grow light in vertical farming in a dark and/or shaded environment with artificial lighting using LED and to develop a simple structure which can give maximum yield with minimum inputs. Two studies were carried out, in the first study coriander was selected as the crop and the experiment was done under complete dark environment. Later another study was made with amaranthus under a shaded condition. For both the experiments biometric observation of the crops were taken and their results are discussed in this chapter.

4.1 Study with coriander in dark condition

4.1.1 Light Intensity

The measured light intensity inside the room supplemented with grow lights within the range of 400-500 lux.

4.1.2 Growth parameters

4.1.2.1 Plant height

Plant height of coriander was influenced by the exposure to different LEDs. The values of plant height observed are given in Table 4.1. The observations were made at 5, 10 and 15 days after planting (DAP). Based on the observations taken two-way ANOVA without replication was done and the results are shown in Table 4.

From the ANOVA it can be seen that there is significant difference in the plant height under various treatments. The variations of plant heights are shown in Fig. 4.1 for different treatments and growth stages. It is evident that plants under treatment T8 (red- blue& vermiculite -perlite) have a maximum height at all growth stages, whereas the treatment T6 (red & coco peat) shown less increment in height.

Use of red light recorded lower plant heights compared to that with blue and red-blue combination.

Table 4.1. Effect of different treatments on plant height (cm) of coriander

Treatment	Days after planting		
	5	**10**	**15**
T1	4	10.16	12.25
T2	4	10.25	13.25
T3	4	9.1	10.84
T4	4	9.2	10.64
T5	3	9.5	11.65
T6	5	8.5	10
T7	5	11.25	13.52
T8	5	11.5	13.95
T9	3	9.8	12.35

Table 4.2. Analysis of variance of plant height (coriander) in response to different treatments (significant at 5% level)

Treatments	Count	Sum	Average	Variance
T1	3	26.41	8.80	18.40
T2	3	27.5	9.20	22.27
T3	3	23.94	7.98	12.64
T4	3	23.84	7.95	12.20
T5	3	24.15	8.05	20.28
T6	3	23.5	7.83	6.58
T7	3	29.77	9.92	19.47
T8	3	30.45	10.15	21.39
T9	3	25.15	8.38	23.36
5 DAP	9	37	4.11	0.61
10 DAP	9	89.26	9.92	0.99
15 DAP	9	108.45	12.05	1.89

Source of Variation	SS	df	MS	F	P-value	F crit
Treatments	18.56056	8	2.32007	3.985656	0.008967	2.591096
DAP	303.8691	2	151.9346	261.0088	6.12E-13	3.633723

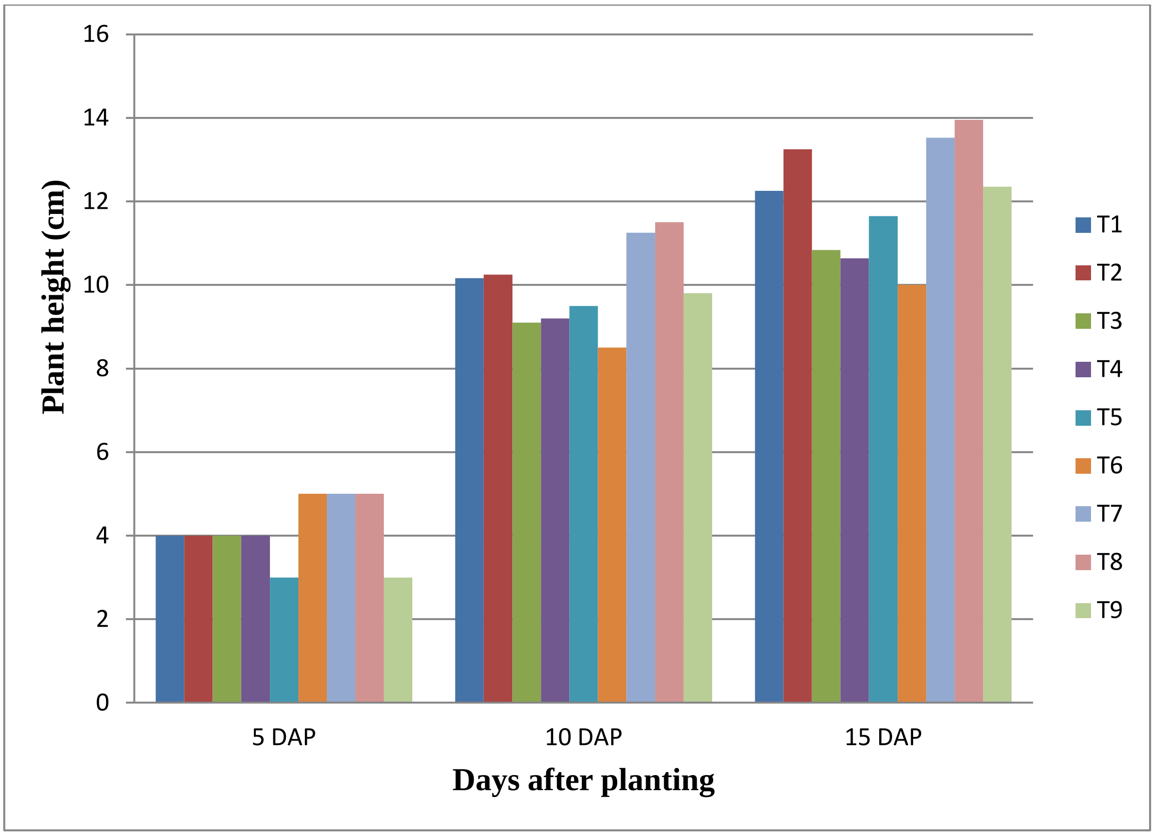

Fig. 4.1. Effect of different treatments on plant height (cm) in coriander

Generally plants treated with vermiculite perlite mixture shown higher heights under different light conditions in all growth stages, whereas the plants in coir peat shown less increment in plant height compared to other media. The plants grown under the red and blue combination shows a maximum height compared to those with red and blue alone as light treatments. This is in agreement with Bula *et al*. (1991).

4.1.2.2 Number of leaves

The data on number of leaves were recorded at 5th, 10th and 15th days after planting (Table 4.2) revealed that the different light treatments has not much influenced the leaf production.

From the ANOVA it can be seen that there is no significant effect of light application on number of leaves under various treatments. The variations in number of leaves are shown in Fig. 4.2 for different treatments and growth stages. Even though the lighting and media has no significant effects on leaf production, highest number of leaves were observed under treatment T7 followed by T8 on 15 DAP.

Table 4.3 Effect of different light treatments on number of leaves of coriander

Treatments	Days after planting		
	5	10	15
T1	3	5	6
T2	3	5	5
T3	4	4	6
T4	4	5	6
T5	3	4	7
T6	4	4	6
T7	3	6	8
T8	4	5	7
T9	3	4	5

Table 4.4. Analysis of variance of number leaves (coriander) in response to different treatments (significant at 5% level)

Treatments	Count	Sum	Average	Variance
T1	3	14	4.67	2.33
T2	3	13	4.33	1.33
T3	3	14	4.67	1.33
T4	3	15	5	1
T5	3	14	4.67	4.33
T6	3	14	4.67	1.33
T7	3	17	5.67	6.33
T8	3	16	5.33	2.33
T9	3	12	4	1.00
5 DAP	9	31	3.44	0.28
10 DAP	9	42	4.67	0.5
15 DAP	9	56	6.22	0.94

Source of Variation	SS	Df	MS	F	P-value	F crit
Treatments	6	8	0.75	1.542857	0.218872	2.591096
DAP	34.88889	2	17.44444	35.88571	1.22E-06	3.633723

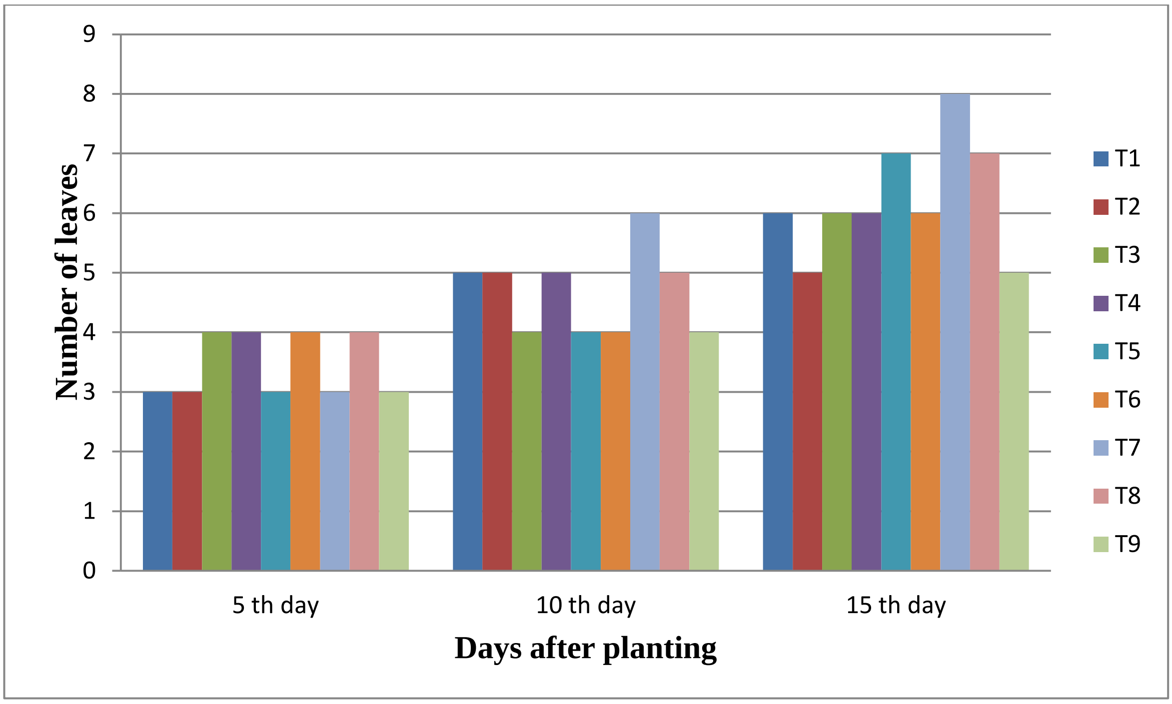

Fig. 4.2. Effect of different treatments on number of leaves in coriander

4.2 Study with amaranthus in shaded condition

4.2.1 Light intensity

The measured light intensity inside the shaded room supplemented with grow lights (LED and fluorescent light) was within the range of 5000-25000 lux.

4.2.2 Growth parameters

4.2.2.1 Plant height

The observations on plant height were made on 10, 20 and 30 DAP and the values are given in Table 4.5.

Table 4.5 Effect of different treatments on plant height (cm) of amaranthus

Treatment	Days after planting		
	10	**20**	**30**
T1	7.28	10.16	16.33
T2	8.23	10.25	18.66
T3	4.15	9.19	10.67
T4	4.12	6.28	8.33
T5	10.15	13..5	14.66
T6	6.81	8.51	9.67
T7	14.78	19.25	26.35
T8	15.38	19.18	26.33
T9	12.08	16.8	18

Based on the observations two-way ANOVA was done to find out the variation among plant height under different treatments and the results are shown in Table 4.6. The variations of plant heights are shown in Fig. 4.3 for different treatments and growth stages.

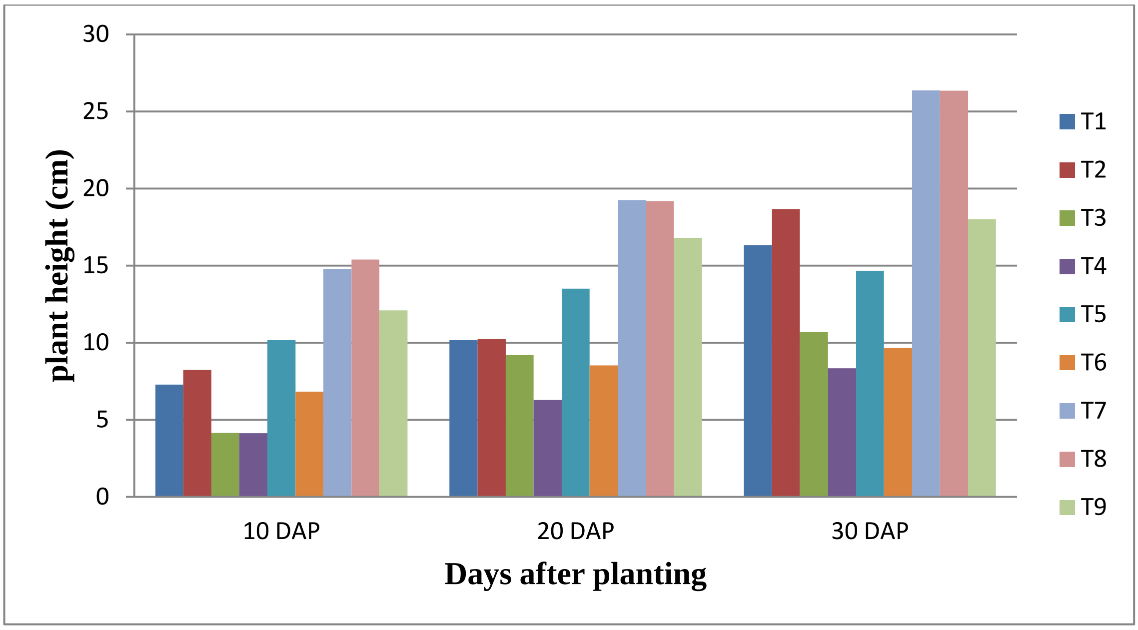

Fig 4.3. **Effect of different treatments on plant height (cm) in amaranthus**

From the ANOVA it can be seen that there is significant difference in plant height under various treatments. It is evident from the results that plants under treatment T7 and T8 have a maximum height at all growth stages, whereas the treatments T4 and T6 have shown lesser increment in height. In general application of red light recorded lower plant heights compared to that with blue and red-blue combination

In general plants treated with vermiculite perlite mixture shown higher heights under different light conditions in all growth stages, whereas the plants grown in coir peat shown less increment in plant height compared to other media. The plants grown under the red and blue combination shows a maximum height when compared to red and blue alone as light treatments. This is in agreement with Bula et al. (1991).

Table 4.6. Analysis of variance of plant height (amaranthus) in response to different treatments (significant at 1% level)

Treatment	Count	Sum	Average	Variance
T1	3	33.77	11.26	21.38
T2	3	37.14	12.38	30.59
T3	3	24.01	8.00	11.69
T4	3	18.73	6.24	4.43
T5	3	38.31	12.77	5.48
T6	3	24.99	8.33	2.07
T7	3	60.38	20.13	34.04
T8	3	60.89	20.30	30.91
T9	3	46.88	15.67	9.79
10 DAP	9	82.98	9.22	17.52
20 DAP	9	113.12	12.59	23.22
30 DAP	9	149	16.56	43.92

Source of Variation	SS	Df	MS	F	P-value	F crit
Treatments	619.2149	8	77.40187	21.34092	3.78E-07	3.889572
DAP	242.7568	2	121.3784	33.46595	1.92E-06	6.226235

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4.2.2.2 Number of leaves

The data on number of leaves were recorded on 10, 20 and 30 days after planting and are given in Table 4.7. From the results it can be seen that the different light treatments influenced the leaf production.

Table 4.7 Effect of different treatments on number of leaves per plant in amaranthus

Treatments	Days after planting		
	10	**20**	**30**
T1	8.57	14.15	20.66
T2	18	25.46	29
T3	10.01	16.57	20.67
T4	5.68	8.35	10
T5	10	14.36	18
T6	3.9	7	8.33
T7	23.5	34.35	45.66
T8	25.3	35.64	44.66
T9	22.6	33.46	40.66

Based on the observations two-way ANOVA was done to find out the variation in number of leaves per plant under different treatments and the results are given in Table 4.8.The results indicate that there is a significant difference in number of leaves per plant among various treatments. The variations of number of leaves are shown in Fig. 4.4 for different treatments and growth stages. From the results it is evident that plants under treatment T7 and T8 have maximum number of leaves at all growth stages, whereas the plants under treatment T6 have less number of leaves. In general application of red light with cocopeat-cowdung mixture as growing media recorded less number of leaves compared to that with blue and red-blue combination.

Table 4.8. Analysis of variance of number of leaves (amaranthus) in response to different treatments (significant at 1% level)

Treatments	Count	Sum	Average	Variance
T1	3	43.38	14.46	36.61
T2	3	72.46	24.15	31.53
T3	3	47.25	15.75	28.91
T4	3	24.03	8.01	4.75
T5	3	42.36	14.12	16.04
T6	3	19.23	6.41	5.17
T7	3	103.51	34.50	122.78
T8	3	105.6	35.20	93.85
T9	3	96.72	32.24	82.66
10 DAP	9	127.56	14.17	67.53
20 DAP	9	189.34	21.04	129.29
30 DAP	9	237.64	26.40	205.79

Source of Variation	SS	Df	MS	F	P-value	F crit
Treatments	3052.863	8	381.6079	36.33203	7.86E-09	3.889572
DAP	676.5654	2	338.2827	32.20713	2.46E-06	6.226235

Generally plants treated with vermiculite perlite mixture shown large number of leaves per plant under different light conditions in all growth stages, whereas the plants in coir peat shown less number of leaves per plant. The plants grown under the red and blue combination shows a more leaf count compared to those with red and blue alone as light treatments. These results are in agreement with Bula et al. (1991), Lee et al. (1999) Böhme et al. (2001, 2008), Ikeda et al. (2001) and Gao et al. (2010).

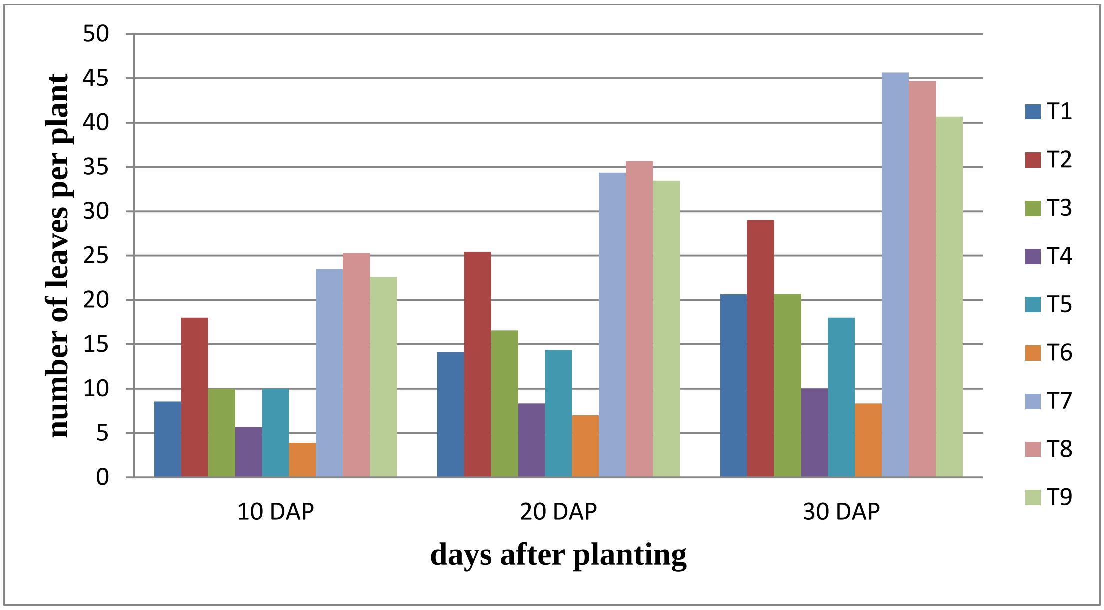

Fig 4.4 Effect of different treatments on number of leaves per plant in amaranthus

4.2.3 Yield parameters

4.2.3.1 Leaf area

The leaf area measured in square centimeters under various treatments is shown in Table 4.9.The area was measured after the final picking (30 DAP) and the average values are expressed under various treatments.

Fig. 4.5 shows the variation of leaf area in response to different light and rooting media combinations. Among the different treatments, plants under T8 shown maximum value for average leaf area followed by T7. That is maximum leaf area was obtained under red- blue combination of light and the least for blue. Views of crop stand under different treatments is shown in Plate 4.1

Table 4.9.Effect of different treatments on yield parameters of amaranthus

Treatment	Parameter	
	Leaf area(cm^2)	Fresh weight(g/plant)
T1	12.00	14.00
T2	19.66	20.00
T3	10.00	12.33
T4	12.66	15.66
T5	15.33	19.66
T6	12.33	14.66
T7	31.00	28.33
T8	42.33	38.33
T9	23.66	20.33

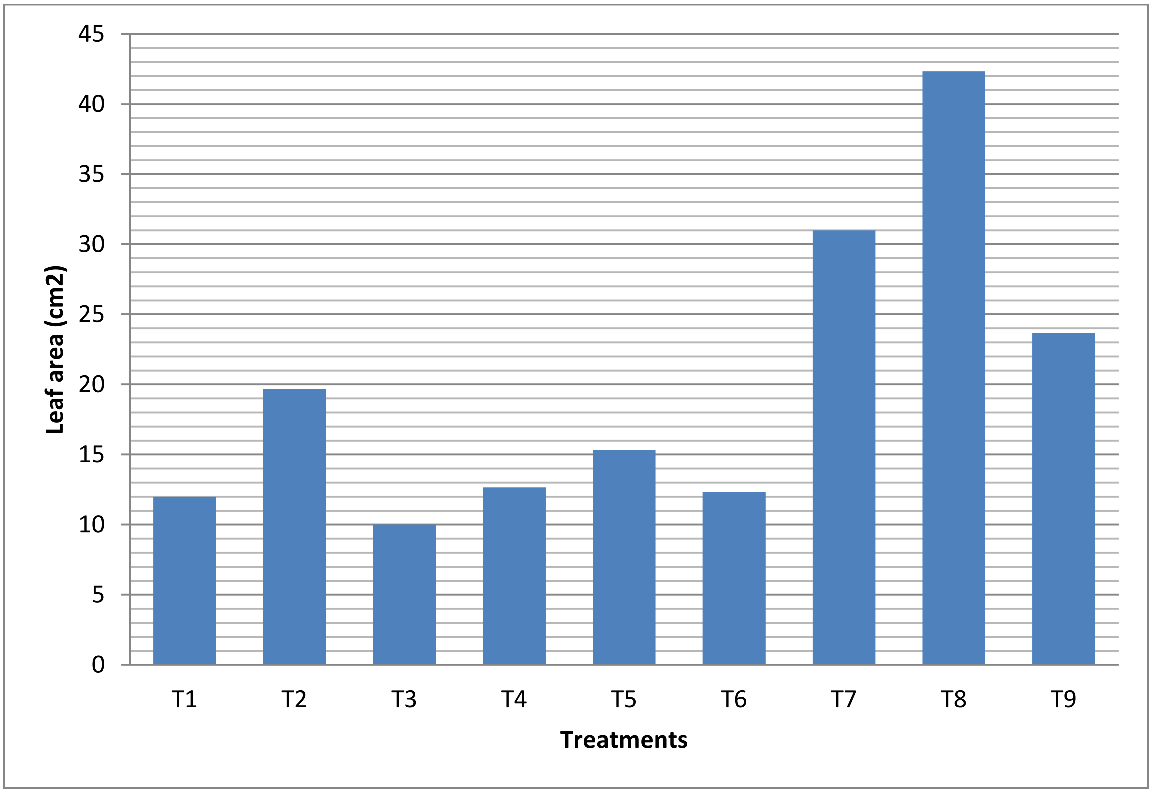

Fig. 4.5 Effect of different treatments on leaf area (cm^2) in amaranthus

4.2.3.2 Fresh matter production

The fresh matter production (FMP) was influenced by both light and rooting media which is given in Table 4.9 and the results revealed that there was considerable variation in biomass production. Generally the FMP was higher in plants under red and blue combination when compared to red light alone. Variation of fresh matter production is graphically shown in Fig.4.6.

Plate 4.1 Crop stand under different treatments

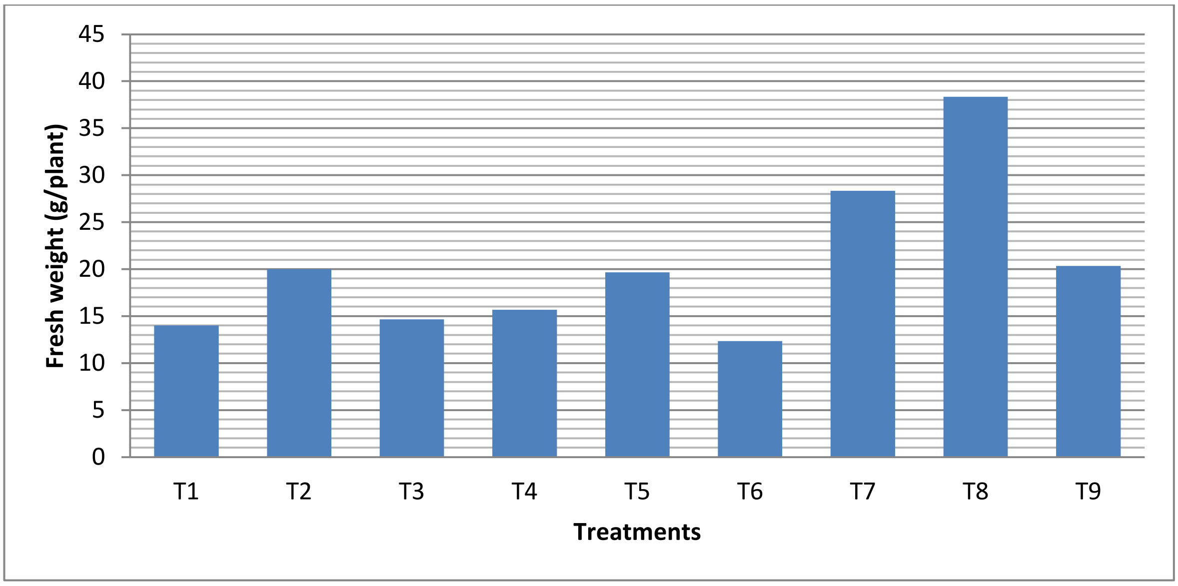

Fig.4.6 Effect of different treatments on fresh matter production (g/plant) in amaranthus

The highest fresh matter production was observed in plants treated with red-blue combination of light in vermiculite-perlite-sand mixture (T8) followed by that in vermiculite-perlite media under the same lighting (T7). The least fresh matter was obtained in plants under treatment T6 that is with red light and coco peat mixture as the medium. All other treatments, i.e. T1, T2, T3, T4, T5 and T9 have shown an intermediate range of fresh matter production. This revealed that the red and blue combination of light has the highest influence on biomass production, whereas red , blue lights alone have no significant effect.

SUMMARY AND CONCLUSION

CHAPTER 5

SUMMARY AND CONCLUSION

The study entitled “Impact of grow lights on plant growth in vertical farming under simulated growing environment” was made to develop a vertical farming structure with artificial lighting using grow lights, suitable for cultivation in shaded areas. Structure was installed inside a room and studies were conducted under complete dark condition supplemented with LEDs and in a shaded condition with light supply using LEDs and fluorescent lamps.

Coriander was selected for the study inside complete dark condition and later amaranthus was used for the study inside shaded region. In both studies the seedlings were raised in pro trays and transplanted at the 4 leaves stage. Three rooting media were used under different treatments viz. vermiculite and perlite in 2:1 ratio, vermiculite, perlite and sand in 2:1:1 ratio and coco peat, cow dung in 3:1 ratio. Irrigation was given once in two days using drip irrigation system. Nutrients were supplied once in two weeks.

Biometric observations such as plant height and number of leaves were made in randomly selected plants from all the treatments on 5, 10 and 15 DAP for coriander and 10, 20 and 30 DAP for amaranthus. Analysis of the results revealed that in the case of coriander different treatments have no effect on number of leaves produced but there is a significant effect on the plant height. Plants under T7 and T8 showed relatively greater height than plants under remaining treatments. The highest plant height obtained on 15 DAP was 13.95 cm in T8, followed by 13.52 cm in T7 and the least recorded value was 10 cm in T6. This leads to the conclusion that red-blue combinations of light have more effect on plant growth than red or blue lights alone. The use of vermiculite, perlite mixture accelerates the plant growth since it imparts good aeration inside the root zone. This experiment was done under complete dark condition supplemented with grow lights. Due to less availability of luminance (400-500 lux) that is not optimum for the biomass production inside the structure, there was no appreciable crop yield. Even under limited light availability plants shown growth response, which provides scope for further improvement.

Analysis of the results obtained from study with amaranthus revealed that there is significant correlation between the plant growth and applied light condition. Plants under T7 and T8 showed maximum height than plants under remaining treatments. The highest plant height obtained on 30 DAP was 26.35 cm in T7, followed by 26.33 cm in T8 and the least recorded value was 8.33 cm in T4. This shows similar trend as in the case of coriander plants. In this case also the use of vermiculite, perlite mixture enhanced the plant growth since it provides a better root zone environment with good aeration and fair amount of water holding capacity. In addition to better water holding capacity, vermiculite and perlite possess good drainability, which might have helped the establishment of good root system and enhancement of overall growth. These treatments were done inside a room where direct sunlight is not available, which is supplemented with LEDs and fluorescent lamps to provide the sufficient luminance for plant growth and biomass production. There was a remarkable increment in number of leaves produced and the leaf area at all stages of growth. The average number of leaves were counted from three plants selected randomly under each treatment and maximum number of leaves at the final picking (30DAP) was 45.66 in T7 followed by 44.66 in T8. Maximum average leaf area was also obtained in T8 followed by T7 with values 42.33 cm^2 and 31 cm^2. Number of leaves as well as leaf area observed in plants under red and blue light treatments was found to be lesser. Fresh matter production in amaranthus on 30 DAP was maximum under T8 and T7 with an average yield of 38.33 g/plant and 28.33 g/plant respectively.

From the results obtained from the study, it can be concluded that direct sunlight exposure is not at all necessary for plants as the photosynthesis and plant growth depends only on the PAR range. Providing PAR in the form of artificial light with sufficient luminance can support plant growth.

Analysis of the results obtained from the trials revealed that grow light based vertical farming can be recommended for indoor precision farming in urban areas as a substitute to the conventional farming practice on limited land area. There is scope for accommodating more number of plants per unit area and performance of individual plants can be improved by adequate access for light and through proper management of growing environment. Scope for further study includes the following.

1. Studies using different plants and cultivation techniques such as hydroponics, aquaponics, aeroponics etc.
2. Studies using improved portable structures with insect proof nets.
3. Studies on automation of irrigation and lighting systems.

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IMPACT OF GROW LIGHTS ON CROP PERFORMANCE UNDER SIMULATED GROWING ENVIRONMENT

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ABSTRACT

Submitted in partial fulfillment of the requirement for the degree of

BACHELOR OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

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2016

ABSTRACT

The study entitled "Impact of grow lights on plant growth in vertical farming under simulated growing environment" was undertaken with the objective to develop a vertical farming structure with artificial lighting using grow lights suitable for cultivation in shaded areas. For analyzing the impact of grow lights on plant growth, artificial lighting sources such as LEDs and fluorescent lamps were provided in the structure and biometric observations were made under 9 treatments with different combination of light (red, blue and red-blue combination) and rooting media (vermiculite, perlite, sand and coir peat). Two studies were conducted, one under complete dark condition with LED as the only lighting source with coriander plants (Co1 variety) and other under shaded condition supplemented with LED and fluorescent light with amaranthus plants (Kannara local). The overall growth of coriander and amaranthus was noted over a period of 15 and 30 days respectively. Results of the first study revealed that in the case of coriander, different treatments have no significant effect on number of leaves produced but has significant effect on the plant height and the maximum plant height was obtained under treatments T_7 (red-blue combination of light and vermiculite-perlite-sand medium) and T_8 (red-blue combination of light and vermiculite-perlite medium). Results of the second study with amaranthus revealed that there is significant correlation between plant growth and applied light condition. Plants under T_7 and T_8 showed maximum height and number of leaves than the plants under remaining treatments. In both studies plants showed a positive response to artificially supplied grow lights especially to red-blue combination. The use of vermiculite, perlite mixture enhanced the plant growth in both cases as it provides a better root zone environment with good aeration and fair amount of water holding capacity along with good drainability. Hence from the study it can be concluded that direct sunlight exposure is not at all necessary for plants, as the photosynthesis and plant growth depends only on the PAR range. Providing PAR in the form of artificial light with sufficient luminance can support plant growth and vertical farming structure with grow light under controlled growing environment can make urban indoor farming a great success