The Effects of Controlled Lighting and Drip Irrigation to the Growth of Lettuce Plants

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***Abstract*— Two major factors for plant growth is the light and water. Based on results of various studies and experiments, exposing the plant to specific blue to red light ratio greatly affects the growth. Irrigation is another essential in plant growth. Studies show that through proper irrigation, higher quality of crops can be achieved. This study explores the effects of controlled lighting and drip irrigation within a controlled environment plant chamber. Each variable is treated as an independent variable and was statistically analyzed to show if controlling that variable significantly affects the growth of lettuce plants. Using Principal Component Analysis, results show that lighting has greater effect in plant growth when compared to irrigation.**

***Index Terms*— cultivation, drip irrigation, growth, lighting, lettuce**

I. Introduction

Light serves a vital role for plant's development. Plants uses light as their source for energy and survival. Light can be the start of the process of photosynthesis that transforms light energy to chemical energy and leads to the production of glucose that gives the plant sustenance, enabling it to live, develop and replicate [1].Various signs a plant will have if it is obtaining too little light is that their stems will be leggy or extended, yellow and too little leaves, spindly leave or stems, tips or edges on leaves will turn brown, dried lower leaves and the deficiency of variegation on variegated leaves [2].

Numerous effects based from various sources show how light may affect different qualities or features of plants throughout the whole cycle of its cultivation period. The quality of different colors or wavelengths of light have distinctive effects on plants. Ultraviolet light can cause harm to the DNA of plants, lessens rate of photosynthesis, reduction of flowering and pollination and can cause influence to seed development. The process of photosynthesis is more effective in blue lights, which also helps in the vegetative and leaf growth of plants. This light is also vital in seedlings or early growing plants since it decreases plant stretching. A phytochrome is a photoreceptor inside the leaves which is discovered to be more responsive to red light, since it is also vital in the control of flowering and fruiting and it also enhance stem diameter and improves branching. Far red light produces elongation in plants and initiates flowering in long-day plants [3].

Other research includes additional special properties of plants that directly stimulates due to the effects of light. This comprises of the germination of seeds (photoblasty and photodormancy) and growth development of stem and leaves in the direction of visible light (etiolation and phototropism) [4].

Irrigation is a vital thing needed in the industry of agriculture. Irrigation is a process for the production of crops in agriculture where the water is distributed to the plants for its needed nutrients. A good process of irrigation leads to a higher quality of crops. It also helps the plants to withstand seasonal variability and drought [5]. Irrigation has different types which includes terraced irrigation, ditch irrigation, central pivot irrigation, sprinkler irrigation and drip irrigation. Ditch irrigation is a type of irrigation where a water drainage is cultivated and plant seeds are sowed and placed in a row. In terraced irrigation, the land is trimmed into treads and the horizontal levelled land is utilized for cultivating plants [6]. In a sprinkler system, water is distributed into plants using sprinklers with high in pressure and is placed at the center of the farm or grassland or in a moving surface. Center pivot irrigation is used in which the water is distributed using a wheeled tower that moves in circular or rotating motion [7].

Drip irrigation is the most practical method in saving water. It allows droplets of water to flow directly into the root areas of a crop [6]. The conventional and other techniques of watering plants are cheaper, but they are almost as practical as current techniques [8]. Studies about automated irrigation is improved for saving water efficiently. There are some procedures that can be utilized to manage the watering of plants. The Internet of Things (IoT) has been utilized to manage and observe the irrigation process remotely [9] [10] [11]. ANFIS (an adaptive-network-based fuzzy inference system) can include both neural networks and fuzzy logic rules. It can create the choosing of the rule base more modifiable to the problem [12] [13] [14]. The Fuzzy Logic Algorithm resembles human intelligence. Fuzzy logic uses the levels of likelihoods of inputs to obtain the definite output [15] [16] [17].

The focus of this experiment is to study only the effects of an adaptive lighting system as an alternative light source and automated drip irrigation based from acquired results, which will not include other parameters that may affect the plant's growth. The gathered data will be statistically analyzed using Principal Component Analysis to see the how great the influence of each parameter is to the growth of the lettuce plant.

II. Related Literature

The first study includes analyzing the impacts of light on the biomass and an internal nature of lettuce plants for which is based on four different light quality considerations. The crops were cultivated hydroponically in an environmentally regulated room with every 12 hours of exposed light, below temperatures of 18 ± 1°C and 20 ± 1°C and a value of 300 μmol m-2 s-1 of photosynthetic photon flux density (PPFD). These four distinctive color radiations include blue illumination from blue fluorescent lights (B), red illumination from red fluorescent lights (R), a blend of both red and blue illumination (RB) and white illumination from white fluorescent lights (W). Results from the data reveals that the illumination of B or RB contrasted with W enhanced the substance of L-ascorbic acid in the lettuce but diminished its nitrate content. This concludes that proper regulation of the quality of light is very effective in helping the lettuce plant to accomplish greater productivity and greater nutritional quality even below restricted amount of light intensity in an isolated or environmentally regulated farming facilities [18].

The set-up of the second system involves the utilization of both LED lights and fluorescent lights to be radiated on lettuce plants to compare the results of their effects. On LED lights, these were tested out on monochromic and blended radiation of blue, green and red illumination. Results show that monochromic red illumination improved the photosynthetic rate of lettuce with also the same output from the impacts of blended illuminance of red and blue radiations. However, the amount of leaves diminished in monochromic blue light and the dry weight rate crucially lessened from monochromic red light. Still, the fresh weight of lettuce expanded from both monochromic red radiation and fluorescent lamps. With respect to conserving the amount of energy, LED is much more efficient than fluorescent lights, since it is also has smaller bandwidth than fluorescent lights which helps to give more emphasis on specific ranges of the light spectrum required for photosynthesis [19].

A study focused on the effects of LED lighting which has proven useful especially in growing a Lettuce plant. It can increase the anthocyanin that is good for health and can control the production of plants. The amount of color was determined under five different lighting conditions as seen in Table I. The output is in the range of 0 to 255, where 0 represents the amount of black and 255 represents the amount of white.

TABLE I. Different Light Treatments

Light Treatment	Blue	White	Red
0% Blue	0	20	230
8% Blue	20	20	210
16% Blue	40	20	190
24% Blue	60	20	170
32% Blue	80	20	150

Using the blue, white, and red color of LED it forms five treatments with a different value. The white light remains in the intensity of 20 while the blue light is in interval of 20 and the red is in decreasing order. As a conclusion, 40 to 60 μmol•m-2•s-1 have the best result for the height while 60 μmol•m-2•s-1 is the best for biomass [20].

Numerous studies about the automation of a drip irrigation system were conducted and implemented to control the flow of irrigation using different methods. One of these studies by Paucar, et al., used decision support to automate the watering of plants by using wireless distributed sensors. The objective of the study is to develop a system for smart irrigation which will evaluate the irrigation time. The input parameters of the system are temperature and humidity values in order to obtain the irrigation time. However, the system developed has a time-based output wherein the pressure of irrigation is not constant [21].

Another study about automation of an irrigation system by Devika, et al., used a microcontroller Arduino and soil moisture sensor to automatically sense the moisture level of soil and to determine when and how much water the plant needs. The system relies on the moisture content of the soil, if the moisture content is less than the required moisture, the system will start irrigating the plants with the required amount of water. This system might have inaccurate data since it used only one parameter which is the moisture content of soil [22].

A study by Anand, et al., used fuzzy logic to optimize the used of water and fertilizer. Their study used a sensor to gather data such as temperature and humidity. It also used a communication link to monitor, control and schedule the system through cellular text messages. In this study, the fuzzy logic is proven to be effective in deciding of how long and how much water will be used. However, this system is a time-based output also, the moisture content of the soil was not considered for input parameters [23].

A Graphical User Interface (GUI) makes it easy to interact with a device or a system so it is important to have a well-designed GUI, several studies were conducted about a drip irrigation system with a Graphical User Interface. Usmonov and Gregoretti designed a GUI app using Kivy, a python framework for GUI application for controlling drip irrigation. Their GUI app has been tested on Linux and Windows wherein the user can edit, add or remove the information of solenoid valves. However, collected data were not included in the app, it can only monitor and control the activities of solenoid valves and pump [24].

Another study was developed by Ishak, et al., wherein irrigation system is conducted with Graphical User Interface (GUI) using Android application in smartphone to monitor and control the watering activity. It can also monitor the light and moisture level of the test field. As a result, it is proved that with a GUI, the user can successfully manage to control and monitor the irrigation system remotely [25].

III. Methodology

Figure 1 shows the general block diagram for the drip irrigation system. Where the First block will decide which water source will be used and the second block is the input to the fuzzy logic. Then the block of valve opening system is responsible for the opening and limitation of the water volume to be distributed to the soil.

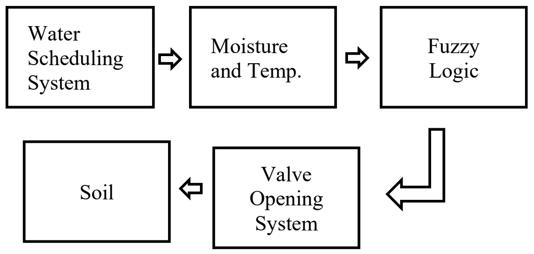

Fig 1. Block diagram for the Irrigation System

A. Experimental Setup

A smart controlled environment chamber with controlled lighting and drip irrigation is design to produce crops at optimum growth. The study used two setups for cultivating the lettuce plants. The first setup will be cultivated in a conventional setup where irrigation will be done manually and natural lighting is used. The second setup will be b9cultivated inside the smart chamber where irrigation is automatic and the lighting is adaptive. Before cultivating the lettuce into the different setups, it will be grown in a rockwool material to ensure sprouting.

B. Lighting System

A vision system is developed to extract relevant plant features and is used together with the lighting system. The lighting system comprises of an algorithm that will determine the correct light setting based on the extracted plant features. It automatically adjusts the light based on the stage of the crop being grown. The study entitled Feature-based Lighting Control for Lettuce plants using Adaptive Neuro Fuzzy Inference System was used in this study to model the algorithm

Figure 2 shows the block diagram of the lighting system. The camera with the Raspberry Pi serves as the data logger and the vision system where it will capture and processes the image of the lettuce to extract the features that will be the input of ANFIS algorithm. The ANFIS algorithm together with the controls to the main lighting will be implemented in an Arduino Microcontroller. An RTC module is also used for scheduling the time where the lighting will turn on or off. The lighting system used Adafruit Neopixel RGB LED which are addressable LED lights. Each individual led can be programmed to produce any color in the RGB scale. All data is stored in an SQL Database

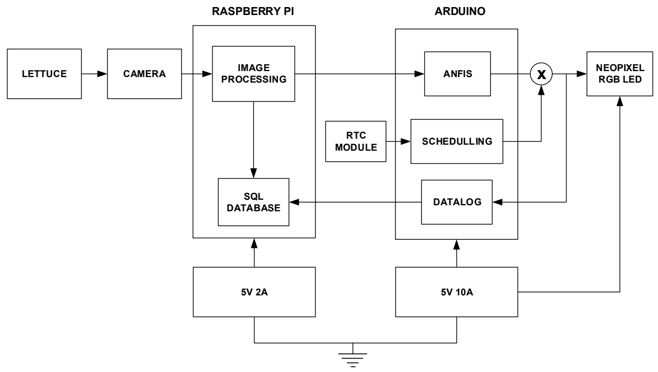

Fig 2. Block diagram for the lighting system.

Table I shows the summary of the lighting characteristics for the lettuce crops. Based on proven experiments, these characteristics greatly affects the growth of plants.

TABLE I. Lighting Characteristics for lettuce crops

Growth Stage	Red – Blue Ratio	Duration (hr/day)
Vegetative	R- 30%; B – 70%	12 to 20
Flower Initiation	R – 50%; B – 50%	12 to 20
Fruit/Seed Development	R – 70%; B - 30%	12 to 20

Figure 3.a and 3.b shows the Fuzzy Inference System and ANFIS Model Structure generated upon training the algorithm.

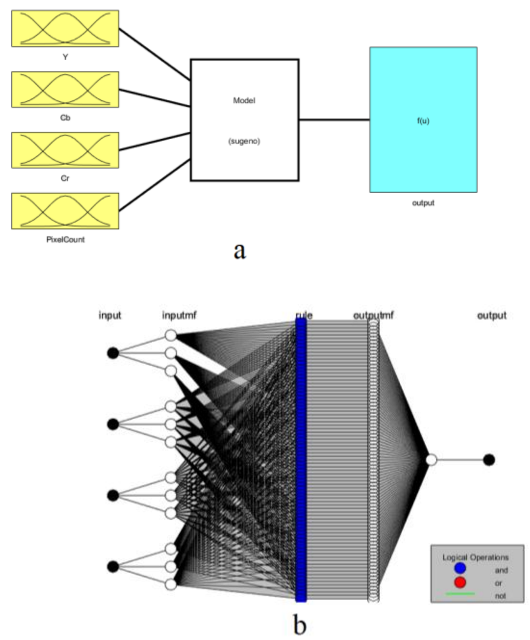

Fig. 3. a. Fuzzy Inference System; b. ANFIS Model Structure

Figure 4 shows the inputs' membership functions. The modeled Fuzzy Inference System used gaus2mf as the membership function as it is the one with the lowest error. Figure 5 presents the different surface plot. Figure 5.a shows the Y vs Cb vs output; Figure 5.b shows Y vs Cr vs output and Figure 5.c shows Cb vs Cr vs output. The last surface plot is Pixel Count vs output.

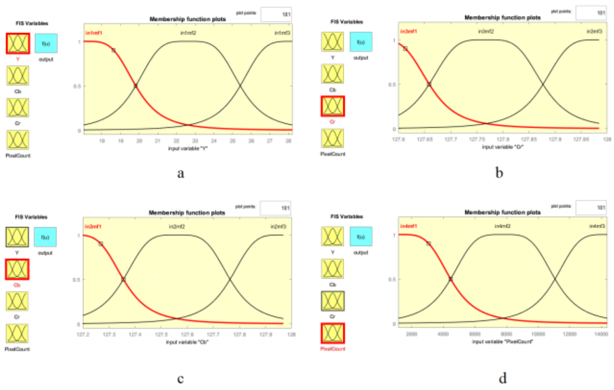

Fig. 4. a. Y membership function; b. Cr membership function; c. Cb membership function; d. Pixel Count membership function

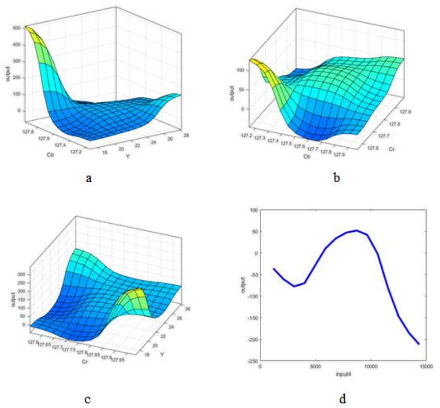

Fig. 5. Input Surface Plot

C. *Drip Irrigation*

Figure 6 shows the main block diagram of the system. The variables employed are moisture of the soil and room temperature. These will be measured by the sensors in each plant bed. Then those parameters will be the input for the fuzzy logic control system. The output data for fuzzy will be the water volume in which the plant needs. Then the valve will open and stops when the resulting volume as indicated by the fuzzy is obtained. The moisture of the soil, temperature and water volume will be shown in an LCD.

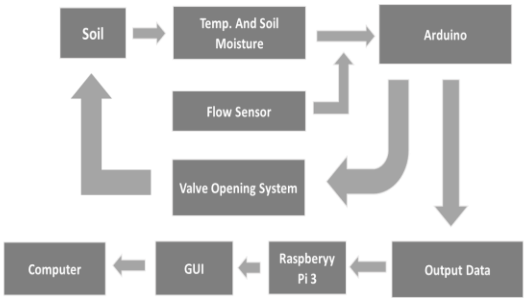

Fig. 6. Block diagram for Drip Irrigation system.

Figure 7 shows the fuzzy logic of the system. The input variables to the fuzzy are the average soil moisture and average temperature. The resulting section is the daiily volume of water.

Fig. 7 Fuzzy Logic System

Figure 8 shows the input membership function of the moisture of the soil. Soil moisture is split into three different membership degrees. The Fuzzy linguistic Variables represents the following: Dry, Moist, Wet. Figure

Fig. 8 Input Membership function for Soil Moisture

Figure 9 shows the input membership function for room temperature. It is split into three degrees of membership and represented as: Hot, Mid, Cold. A membership function which is trapezoidal is employed because it has a lead in terms of comprehensibility and have a wide range.

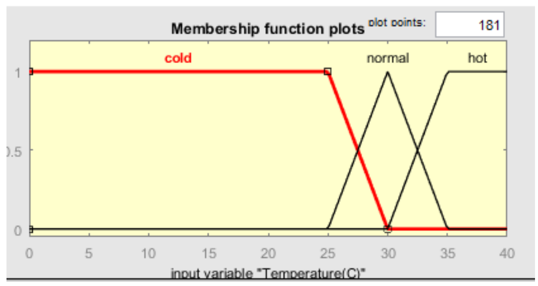

Fig. 9 Input Membership function for Room Temperature

Figure 10 shows the output membership function for the volume of water. Triangular membership function is used for the fuzzy output because of its simplicity and more definite output other than the trapezoidal which has a large range of value. The volume is represented by the linguistic variable of: little, medium, large. The degrees of membership each: [1 3 3 5] for small, [3 5 5 7] for medium, and [5 7 7 10] for large.

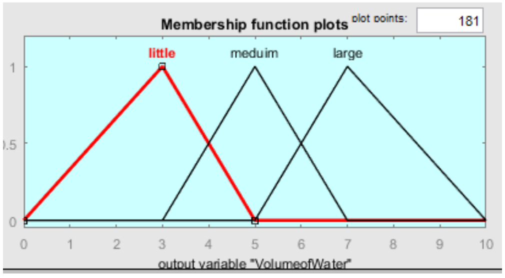

Fig. 10 Output Membership function

IV. Results and Discussion

A. Controlled Lighting

A PAR Sensor connected to a laptop via Go! Link was used to measure the Photosynthetic Photon Flux Density or PPFD of both setups. Table II presents the data gathered from the conventional setup. Figure 9 shows the graph of each measurement from the conventional setup. Due to varying weather conditions, the lighting is not consistent.

TABLE II. Measured PPFD from the conventional setup (umol/m^2/s)

Plant A	Plant B	Plant C	Plant D
41.96	40.87	42.12	43.13
55.48	51.10	51.52	52.09
55.30	51.36	55.41	53.25
48.98	52.17	51.10	50.86
52.81	53.32	54.96	54.64
45.76	40.44	43.74	44.41

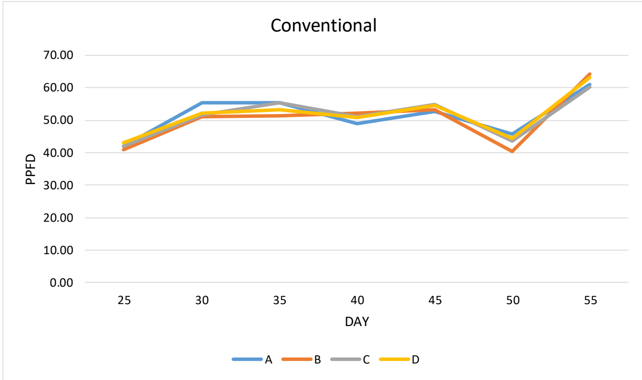

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Fig 9. Measured PPFD from conventional setup

Table III presents the data gathered from the smart chamber setup with its graph shown in Figure 10. Since the design of the chamber is a box with lightning in the sides and top, the lettuce plants receive consistent lighting.

TABLE III. Measured PPFD from the smart chamber setup (umol/m^2/s)

Plant A	Plant B	Plant C	Plant D
41.96	40.87	42.12	43.13
55.48	51.10	51.52	52.09
55.30	51.36	55.41	53.25
48.98	52.17	51.10	50.86
52.81	53.32	54.96	54.64
45.76	40.44	43.74	44.41

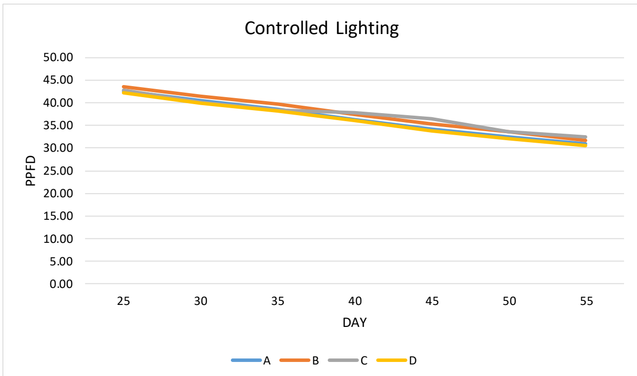

Fig 10. Measured PPFD from smart chamber setup

Comparing the data gathered, the crops grown in the smart chamber has received consistent lighting

B. Drip Irrigation

Table 5 shows the soil moisture measured by the sensors before and after watering inside the chamber. Based on the results, the measured values passed the required moisture for the soil.

TABLE IV. SOIL MOISTURE IN CHAMBER BEFORE WATERING

Growth Stage	Day	Required Soil Moisture	Soil Moisture Before Watering (%)				
			Plant 1	Plant 2	Plant 3	Plant 4	Average
Seed Germination Stage	Day 0	Wet (8-10)	48	48	46	47	47.3
	Day 5		46	45	43	40	43.5
	Day 10		40	38	41	44	40.8
	Day 15		40	43	48	49	45
Growth and Development Stage	Day 20		68	69	65	71	68.3
	Day 25		68	59	66	70	65.8
	Day 30		66	65	58	69	64.5
	Day 35		60	59	60	64	60.8
	Day 40		60	65	63	60	62
	Day 45		63	58	61	-	60.67
	Day 50		66	67	61	-	64.67
	Day 55		63	68	63	-	64.67

TABLE V. SOIL MOISTURE IN THE CHAMBER AFTER WATERING

Soil Moisture After Watering					Remarks
1st Plant	2nd Plant	3rd Plant	4th Plant	Average	
85	88	84	86	85.75	Pass
85	83	82	85	83.75	Pass
87	84	86	88	86.25	Pass
87	88	85	85	86.25	Pass
85	89	88	88	87.5	Pass
91	87	88	86	88	Pass
92	90	84	92	89.5	Pass
87	85	88	85	86.25	Pass
87	95	93	85	90	Pass
85	87	88	-	86.67	Pass
85	86	85	-	85.33	Pass
87	88	88	-	87.67	Pass

C. Principal Component Analysis

Tables VI and VII shows the obtained eigenvalue using Principal Component Analysis. Based on the gathered results, Principal Component (PC) 1 and 2 has attained an eigenvalue greater than 1 which means that only PC1 and PC 2 can be used to describe the variations in the data.

TABLE VI. EIGEN VALUES FOR CONVENTIONAL SETUP

PC	Eigenvalue
1	4.77472461
2	1.19166587
3	0.7882362
4	0.17996369
5	0.05149532
6	0.01347317
7	0.00044114

TABLE VII. EIGEN VALUES FOR CHAMBER SETUP

PC	Eigenvalue
1	4.18821511
2	1.21038214
3	0.96076632
4	0.50899093
5	0.08555984
6	0.04376842
7	0.00231725

Table VIII presents the loadings of principal components 1 and 2 for the conventional setup. Results show that for the conventional setup, both lighting and soil moisture has a relatively low effect on the variation of data.

TABLE VIII. PRINCIPAL COMPONENTS OF CONVENTIONAL SETUP

Variable	PC1	PC2
No. of Leaf	0.469	0.04
Height	0.48	0.037
Diameter	0.479	0.07
Canopy Area	0.469	0.469
Lighting	0.248	0.23
Soil Moisture Before Watering	0.149	-0.718
Soil Moisture After Watering	-0.13	0.638

Table IX shows the loadings of the principal components of the chamber setup. Comparing the results from the conventional setup, the lighting shows greater effect in the variation of data. While both soil moisture maintains a relatively low effect.

TABLE IX. PRINCIPAL COMPONENTS OF CHAMBER SETUP

Variable	PC1	PC2
No. of Leaf	0.447	-0.07
Height	0.455	-0.01
Diameter	0.453	-0.037
Canopy Area	0.431	-0.109

Lighting	-0.428	-0.059
Soil Moisture Before Watering	-0.137	-0.667
Soil Moisture After Watering	0.024	-0.73

V. CONCLUSION

Based on the results of the Principal Component Analysis, lighting obtained a relatively high loading which has a great effect on the variation of data. Since the design of the lighting system is to provide optimum lighting conditions at all times, the light received by the plants is consistent. Conventional setup uses sunlight however, due to varying weather conditions the plant does not received the required lighting for optimum growth. Based on the findings, it can be concluded that by controlling the light, growth of plants can be further optimized and improved resulting to a higher quality crop.

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