



UNIVERSITI PUTRA MALAYSIA

***DESIGN THE PLANTING SYSTEM OF VERTICAL NUTRIENT FILM
TECHNIQUE (NFT) FOR GREEN AND RED LETTUCE PRODUCTION***

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2020

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NUTRIENT FILM TECHNIQUE (NFT) FOR GREEN AND
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By

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A Final Year Project Report Submitted to the Department of Biological &

Agricultural Engineering, Faculty of Engineering, University Putra

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APPROVAL SHEET

I certify that this research project report entitled “**Design the Planting System of Vertical Nutrient Film Technique (NFT) for Green and Red Lettuce Production**” by Maizatul Norsyahidah binti Durimi has been examined and approved as a partial fulfilment of the requirements for the Degree of Bachelor of Agricultural and Biosystems engineering with Honours in Faculty of Engineering, University Putra Malaysia.

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ABSTRACT

A hydroponics planting technique commonly uses mineral nutrient solutions in soil-free water where it is an ideal way to grow vegetables, fruit, and soilless crops. Crops are placed in the growing medium and the nutrient solution are supplied straight to the roots using the hydroponics method. The hydroponic planting system may help in producing a high yield of crops and good quality in a less space area to fulfil the needs of food supply. With respect to other types of hydroponic system such as deep-water culture, the systems normally used a huge amount of water where it may cause a heavy load to the structure. Hence, design of Vertical Nutrient Film Technique (NFT) helps in reducing the structure load such as the amount of water used inside the system and at the same time it will support to produce a better yield. The design of a Vertical NFT frame structure was based on 5 tiers of growing media. The area of structure is 67 m²; 10 m length, 6.7 m height and 1 m width. Every tier of growing media has 250 crops; therefore, the structure can produce 1250 crops. The crops are planted with 20 cm x 20 cm planting spacing. The analysis of the frame is made using RISA 2D. The load imposed on the structure is calculated from the weight of the water, weight of the tray and weight of the plants. From the analysis, it shows that the middle vertical bar has a high force acting on it compared to both end support. The size of vertical frame use is 4 inches x 4 inches to support the loads in the structure. The size of pump needed to pump up the nutrient solution is 0.003 hp where the pump supplies the nutrient solution continuously throughout the system. The One-way ANOVA and mean comparison between groups for green lettuce and red lettuce under LED light shows a significance of ($p > 0.05$) for both.

Keywords: Hydroponics, Vertical Farming, Nutrient Film Technique, Plant Factory, Urban Farming

ABSTRAK

Teknik penanaman secara idroponik biasanya menggunakan larutan nutrient mineral dalam keadaan bebas tanah di mana ia merupakan cara yang sesuai untuk penanaman sayur, buah dan tanaman tanpa air. Tanaman diletakkan di dalam media tanaman dan larutan mineral disalurkan terus ke akar menggunakan cara hidroponik. Sistem penanaman hidroponik boleh membantu dalam menghasilkan hasil tanaman yang tinggi dan berkualiti di dalam ruangan yang kecil untuk memenuhi keperluan bekalan makanan. Berkenaan jenis sistem tanaman hidroponik yang lain seperti "Deep Water Culture". Sistem ini kebiasannya menggunakan kuantiti air yang sangat besar dan boleh menyebabkan beban yang berat terhadap struktur. Oleh itu, reka bentuk struktur tanaman Teknik Filem Nutrient (NFT) secara menegak membantu dalam mengurangkan beban struktur seperti jumlah air yang digunakan didalam sistem dan pada masa yang sama ia akan dapat menghasilkan hasil yang lebih berkualiti. Reka bentuk struktur kerangka Teknik Filem Nutrient secara menegak berdasarkan kepada lima tingkat media penanaman. Keluasan struktur adalah 67 m²; 10 m panjang, 6.7 m tinggi dan 1 m lebar. Setiap tingkat media tanaman mempunyai 250 tanaman; oleh itu, satu struktur mampu menghasilkan 1250 tanaman. Tanaman ditanam dengan jarak penanaman 20 cm x 20 cm. Analisis kerangka struktur dibuat menggunakan RISA 2D. Beban yang dikenakan pada struktur dikira daripada berat air, berat 'tray', dan berat tanaman. Hasil daripada analisis menunjukkan tiang tengah struktur dikenakan daya yang besar berbanding kiri dan kanan tiang sokongan menegak. Saiz kerangka yang digunakan ialah 4 inci x 4 inci untuk menyokong beban struktur. Saiz pam yang diperlukan untuk menyalirkan larutan nutrien ialah 0.003 hp di mana pam akan menyalirkan larutan nutrien secara berterusan di seluruh sistem. Analisis ANOVA sehalu dan perbandingan mean dibuat antara kumpulan untuk salad hijau dan salad merah dibawah pencahayaan lampu LED menunjukkan tiada signifikan ($p > 0.05$) bagi keduanya.

Kata kunci: Hidroponik, Pertanian Vertikal, Teknik Filem Nutrien, Kilang Tumbuhan, Pertanian Bandar

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CHAPTER 1

1.1 Background of the study

Hydroponics is a plant growing technique that uses mineral nutrient solutions in soil-free water.

The hydroponic method is the ideal way to grow vegetables, fruit, and soilless crops.

The hydroponic system needs a consistent accuracy, persistent and close monitoring to avoid the bad impact on the crop, especially for vegetable plants. Small changes in pH, electrical conductivity (EC) in nutrient, the temperature of the water, air temperature and light intensity will affect the quality of the crops (Siregar et al., 2018). Therefore, it is important to control all of these parameters to produce more products with a good quality of crop since it will give a big impact to the plant in its growing process.

Proper guidance is essential in the development and implementation of the hydroponic system. It is important to know how to do the design of greenhouse, environment control also nutrient solution needed by the plant, pest control, crop selections and practices of cultural crops (Jones, 2014).

1.2 Problem statements

Over the last few years, the old farming method increasingly shift toward urban farming method. The design of hydroponic system comes in varieties depends on cultivators needed. Therefore, design of vertical NFT planting system is different compared to the hydroponic method design.

The study related to the design of the vertical Nutrient Film Technique (NFT) system for growing green and red lettuce including of pumping system, lighting system, evaporative cooling system and carbon dioxide enrichment system is very limited. Also, the interaction between green and red lettuce under different type of LED which is white and red blue LED.

1.3 Objectives

The general objective is to design a vertical NFT planting system for growing green and red lettuce.

The specific objective:

- i. To study and design the vertical NFT for growing green and red lettuce which include the pumping system, lighting system, evaporative cooling system and carbon dioxide enrichment.
- ii. To study the most suitable fertilizer mixing for green and red lettuce.
- iii. To study the effect of LED light on green and red lettuce height.

1.4 Significance of study

It is desirable to study on the vertical NFT system design which include pumping system, lighting system, study the most suitable fertilizer system, study the suitable condition of green and red lettuce including of CO₂ system, humidity and temperature control system and root cooling system, in order to get the most suitable planting structure system of vertical NFT.

CHAPTER 2 LITERATURE REVIEW

2.1 Vertical farming

Vertical farming (VF) is a planting method where the crops are planted vertically up to a certain height. The VF structure is built up in many levels vertically consisting of growing beds and artificial light. Vertical farming has many benefits that make it become a popular method to plant especially in the urban area (Fesquet et al., 2016). Normally, the urban area has a limited surface to do agricultural activities like farming. The use of VF might help regarding on this issue since VF is planted in a vertical manner with many levels of plant bed. High yield of the crop in a minimal area can be produced by vertical farming. In detail, 1 acre of indoors area offers the corresponding production to at least 4-6 acres of outdoor capacity. VF plays an important role in helping to supply food demand mainly on crops for the future since it is expected that 80% world population by 2050. Besides that, it is required between 5-30% of the water required for normal cultivation to produce crops in VF (Maria Royston, 2018).

2.2 Nutrient Film Technique (NFT)

Nutrient Film Technique (NFT) is one of the main growing methods used in commercial hydroponic production among the other methods (drip, float system, ebb and flow system, aquaponics, and passive hydroponics). In NFT planting method, crops will be grown inside the gullies and nutrient solution flowing in a thin layer so that the crops root always in a moist condition. Nutrient film technique is preferably for short growing period crops, for instance, leafy crops and herbs. Normally for longer growing period crops are planted using bigger NFT gullies to avoid the root filling the gullies and blocking the flow of water. When the crops are planted using NFT, the crops do not have to be washed as it is already clean and giving one of the benefits to the Nutrient Film Technique growing method compared to other methods (Sheikh, 2006).

This NFT system is working in a closed loop where the water containing nutrient solution is circulated inside the system multiple times. Generally, the nutrient solution will be checked its

electrical conductivity (EC) during circulated. When the EC reading is lower, then the nutrient solution will be added to ensure the initial volume is maintained and to decide when to change to a new nutrient solution into the system. It also stated that crop stage growth is affected by the time and length of nutrient solution flowing inside the system. 'On-off' cycle or 'half-on, half-off cycle' practice has been applied to supply the nutrient solution into the NFT system. It is proven that crops can produce good and high production when using this practice in their planting system. In a closed recirculating system like NFT system is found to be hard to control the disease. This is due to when the disease enters the system, the water flowing will carry the disease organism and will attack the roots of the crop. Hence, it is important to always monitor the nutrient solution before it is flowing inside the system to avoid the spread of root-borne diseases (Jones, 2014).

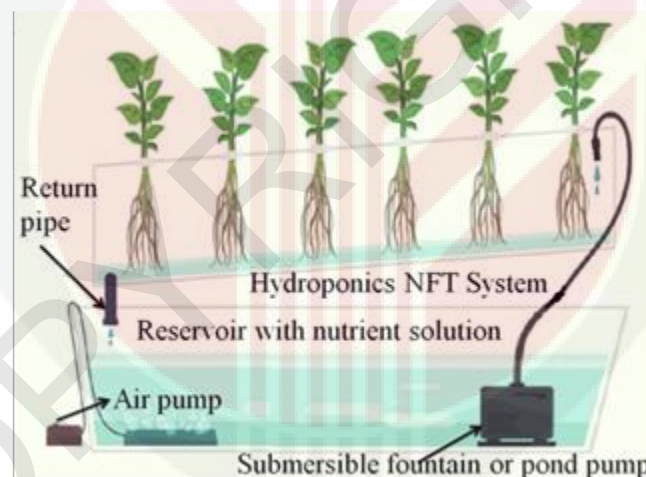


Figure 2.1 Nutrient Film Technique system design (EI-Kazzaz, 2017)

Additionally, NFT shows many advantages compared to another planting system whereas the NFT system has a lesser volume of water and substrate needed. NFT system gives a big impact on reducing water and fertilizer uses and naturally helping in reducing environmental issues (Savvas et al., 2013).

2.3 Planting system for Vertical Nutrient Film Technique (NFT)

2.3.1 Planting structure

In an attempt to design a structure for vertical farming, there are certain criteria have been suggested that need to be adopted to have a successful design. The construction of vertical farming needs to be constructed in multi-storey in a vertical manner and building shape need to be in a rectangular shape. Since the planting structure in a high rise structure, therefore the structure will need to support with a strong core to avoid the structure collapsed due to overload from the load imposed (Maria Royston, 2018).

Graff (2011) shows that there is various type of vertical farming using hydroponics system including A-frame trellis, stacked beds, stacked roller and columnar system. This research paper mentioned that the stacked bed structure system is more straightforward connection to the concept of vertical farming (Figure 2.2). The concept of stacked bed is simply a stacking of the general in-line pip beds to certain height whereas this design becomes the most preferred system used in commercial hydroponic farming.

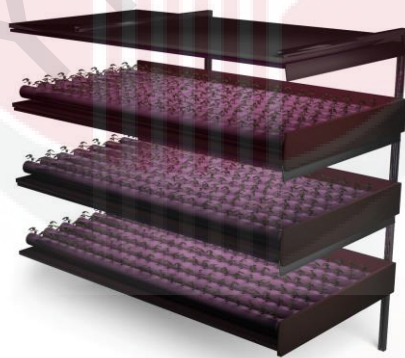


Figure 2.2 Stacked bed planting structure design (Graff, 2011)

To construct the NFT system, the gullies need to design with a small slope to ensure the water flow down to the other gullies until go back to the reservoir (Figure 2.3). When the water reached the reservoir then the pump will be pumped back the water into the upper gullies and

the process repeatable. The gullies normally built up using plastic material like polyvinylchloride (PVC) in a rectangular or triangle-shaped segment. To ensure the flow of water inside the gullies, the base of gullies must be constructed in a flat base since the NFT system is using a shallow depth of water. Indeed, the flow rates need to be controlled in the construction of the NFT system. Flow rates regularly related to oxygenation or nutrient. Water in the gullies will becomes deeper and root oxygen is insufficient if the water flow rate is too fast. On the contrary, when water flow rates are too slow, it can cause nutrient deficiency. As a result, the maximum length of gullies need to in 12-16 meters range otherwise, the rate of nutrient depletion will be higher (Savvas et al., 2013).

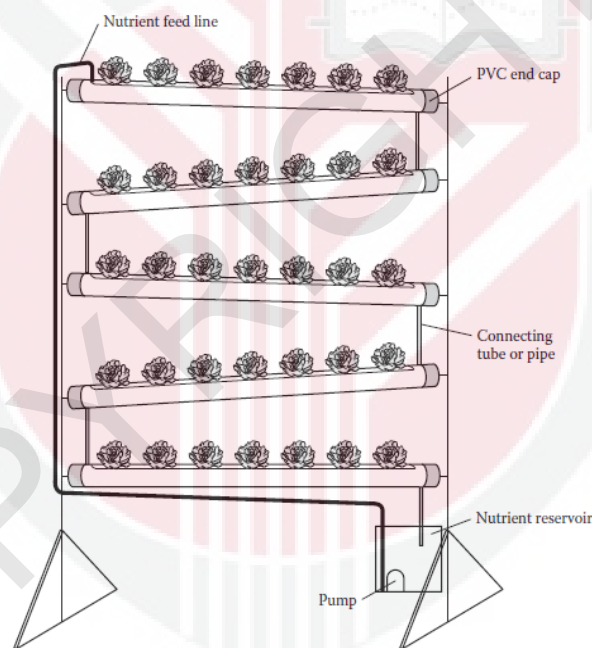


Figure 2.3 NFT system with gradient slope of pipe (Resh, 2013a)

As explained by H. M. Resh (2013a), plant spacing determination is based on the type and size of the matured plant (Table 2.3). Suitable spacing will allow good distribution of light and easy access to the plant during harvesting. It is important to avoid planting different type of crops in the same row because harvesting activities will be difficult to do. Mix crop planting can be done only when it is planted in different rows.

Table 2.1 Recommended plant spacing based on the type of plants (Resh, 2013b)

Type of plants	Recommended plant spacing
Leafy vegetables	6 x 6, 7 x 7, or 6 x 8 inches
Herb	3 x 3 or 4 x 4 inches

Note: Plant spacing may vary according to its variety, final growth, and area of planting unit.

2.3.2 Lighting system

Light is a major environmental factor affecting the herbal plant quality in growth and development where light can help in increasing the phytonutrient level in the plant. In addition to improve the yield and quality under a controlled environment, light-emitting diodes (LED) have been adopted and developed to provide supply targeted phytonutrient accumulation by herbs. A light-emitting diode (LED) that contains a combination of red light and blue light can produce a high crop production for most of the herb species. Meanwhile, if the blue light amount reached a threshold, crop production found to be decreased for various species of crops. Next, when the blue and red light with different BP are combined, this light combination can increase the plant photosynthesis process. It is because the red and blue colour is the most effective spectra in photosynthesis. Therefore, the use of a single colour of light-emitting diode (LED) will not give much impact to the plant growth (Dou et al., 2017).

The use of red and blue light is the most common light used for plant growth since both light-emitting diodes (LED) are energy-efficient compared to other colours. Red and blue light is more photosynthetically efficient compared to green and white light. Nevertheless, red light has shown that its ability to help the plant to elongate more and grow larger than its normal growth rate (Runkle & Bugbee, 2013).

According to Matysiak and Kowalski (2019), red LED shows 29% of effectiveness higher than blue LED light but there is no significant difference between the red LED and white LED. The

LED lighting that supply to the plant at $130 \mu\text{mol}/\text{m}^2\text{s}$ with 16 h photoperiod gives a good impact to the biomass production of leafy vegetables even though the sunlight supply in the greenhouse in low due to winter season. In addition, crops that exposed to the LEDs show that it has a greater leaf chlorophyll content compared to crop growth under natural light. The combination of three LEDs colour proves that the accumulation of chlorophyll is high.

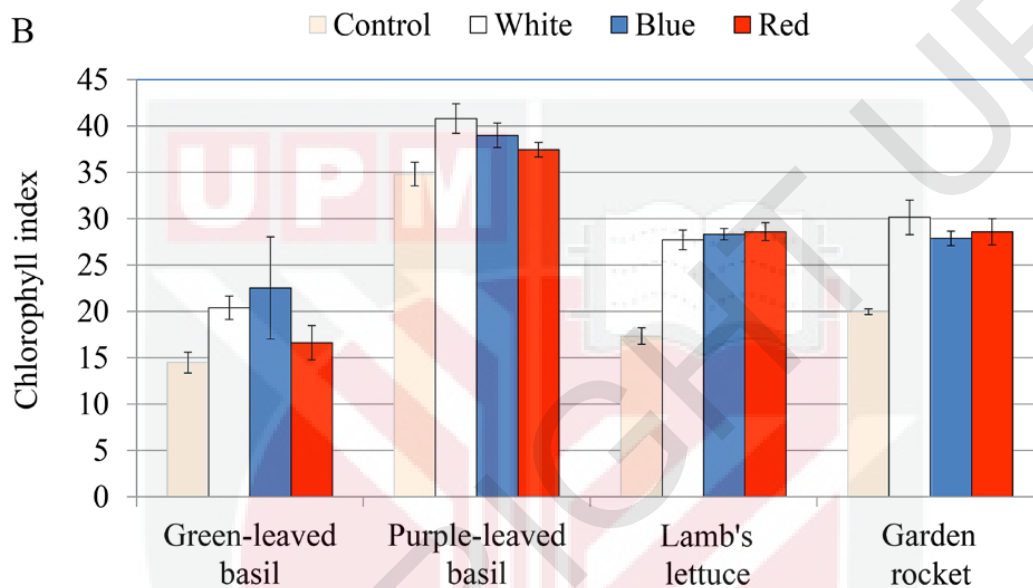


Figure 2.4 Chlorophyll indices (relative units) for basil type and green leafy type of vegetables under supplementary white, blue, red LED light in a greenhouse (Matysiak & Kowalski, 2019)

The general guideline for most vegetables including herbs for the amount of light is around 50 to 70 watts of light per square foot of growing area. During the earlier stages of crop planting, the crop needs to be exposed to the light immediately. Light needs to be placed up to 3 feet (0.9144 m) to get 510-foot candles (5489.59 lux) on the tray surface. A week after the crop growth, the light needs to be lowered down about 1 foot (0.3048 m). Precaution needs to be taken when setting the light to avoid the crops burn which causing from the light if it mounted to close to the plant as the light will produce heat (Resh, 2013b).

An analysis on effect of light intensity towards the plants in term of leaf count, average height and average dry matter content has been conducted by comparing natural lighting and LED lighting. The LED used produces approximately 960 -1080 Lumens (5V,1.4A) and it is placed up to 3m from second pipe. The study state that there are two-fold increments on plant health when using LED lighting compared to natural lighting (Esa et al., 2019).

Additional to that, experiment on lettuce production using artificial light shows that when the light intensity and longer photoperiod, nitrate content will be low. Contracting to that, vitamin C, soluble sugar and protein, and anthocyanin will be higher in that conditions. The most effecting light conditions to produce maximum growth and quality product, PPF: 250 $\mu\text{mol}/\text{m}^2\text{s}$, photoperiod of 16 hour per day under R:B ratio of 2:2 LED is recommended (Zhang et al., 2018).

2.3.3 Nutrient solution

2.3.3.1 Essential element in nutrient solution

In every cycle of nutrient solution in the system, the nutrient content in the solution can be inadequate by times as it is will recycle inside the system. Changes in the nutrient amount in solution give a bad impact on crop performance. In the case of excessive amounts of nutrient in solution, it may harm the crop, waste money and fertilizer resources also causing pollution to the environment. Nutrient needed by the crops may vary according to its growth stages. In the early stages of growth, Nitrogen (N) amount needs to in a correct amount to prevent bullish growth. Bullish growth may affect leaves and stems causing crack and grooves on the stem. Hence, it is important to keep them in a low-level amount of N in other to avoid bullishness problem. At the same time, high potassium (K) content may hinder the crop's ability to absorb calcium (Ca) and magnesium (Mg). Blossom-end rot (BER) often occur to the crops which exposed to excess K. However, the nutrient content also depends on the type of crop planted.

The certain crop will be needed a different amount of nutrient content in its early growth stages (Hochmuth & Hochmuth, 2012).

There are 13 elements (Nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), sulphur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), boron (B), and chlorine (Cl)) should contain in the fertilizer that will be required for a better plant growth (Table 2.2). It is important to measure the elements in the solution for every two weeks and keep the same volume of nutrient to prevent a shortage amount of nutrients needed by the plant. The relevant of maintaining the same amount of water volume is because when the water is below the required volume, the concentration of nutrient will be increase and will affect the root system (EI-Kazzaz, 2017).

Table 2.2 Essential element for most plant (Resh, 2013a)

Element	Symbol	Concentration in dry tissue (%)
Macronutrients		
Hydrogen	H	6.0
Carbon	C	45.0
Oxygen	O	45.0
Nitrogen	N	1.5
Potassium	K	1.0
Calcium	Ca	0.5
Magnesium	Mg	0.2
Phosphorus	P	0.2
Sulphur	S	0.1
Micronutrient		
Chlorine	Cl	0.01

Iron	Fe	0.01
Manganese	Mn	0.005
Boron	B	0.002
Zinc	Zn	0.002
Copper	Cu	0.0006
Molybdenum	Mo	0.00001

Nutrient solution and its concentration may give different effect to the plant growth. A research on determining the plant health (average plant height, leaf number, root length, net weight of the part above the water surface, net weight of the part under the water surface and ratio of the root and the crown) is done by using 12 different types of nutrient solution for one growing season. Every solution is contained with different percentage of the concentration (200%,100%,50% and 25%). The result found that when using 200% concentration of Japanese Garden formula (JG) give the highest average number in term of plant health (Quan et al., 2018).

2.3.3.2 pH of nutrient solution

The pH of nutrient solution needs to measure to check the range of acidity and alkalinity of the solution. For leafy crop, the pH easy to drift because the crop tends to take up a high quantity of negative ion. It is important to maintain between positive and negative ions in the solution as the crop will release negative ions to the water and tend to affect the pH number. Elements like potassium bicarbonate and potassium hydroxide can be used for raising the pH meanwhile, pH can be reduced by using phosphoric acid or nitric acid (Parks & Murray, 2006).

Performance test for remote monitoring system using sensor for three different plants (lettuce, red spinach and Pak Choy) shows that there is decrement in pH levels from day 1 until day 7

of experiment. The changes of pH are the indicators to the nutrient availability in the solution. From the findings, the result determined that every plant need different suitability in pH conditions in helping nutrient uptake (Siregar et al., 2018).

2.3.3.3 Electrical conductivity (EC) of the nutrient solution

Electrical conductivity is a measure of nutrient's solution concentration ability to conduct the electric. As the nutrient solution contains a variety of element, therefore it has the capability to conduct the electricity. Usually, EC meter was used to take the reading of EC for the nutrient solution (Resh, 2013b).

Higher EC reading can be detected if the nutrient solution has a high solution content. Value from the EC meter indicates the total strength of the solution but will not tell on nutrient balance. The target of EC is depending on type plants, growth stage, and climate. Units of measurement of EC include deciSiemens per metre (dS/m) or total dissolved solids (TDS) in parts per million units (ppm) (Parks & Murray, 2006).

When the ratio of nitrogen to potassium is higher, EC values for the nutrient solution will be low. To take the EC values reading, it is important to check the surrounding temperature around 25°C otherwise correction factor needs to be used (Resh, 2013a).

2.3.4 Humidity and temperature control

To improve the growth performance of crops, it is important to control the humidity and temperature surrounding. Appropriate humidity and temperature of surroundings helpful in producing a better yield and good quality of crops. Usually, for a closed system in a small space does not need a humidifying system as the evaporation from nutrient solution can act as a humidifier to the crops. In the cases of a closed loop in a large place, a humidifier is needed to control the surrounding. As the sensor detects low humidity than lower limit inside the room, it will give the signal to the air conditioner to supply more humidity. The air conditioner will

stop functioning when the humidity detects the humidity inside the room is beyond the upper limit (Quan et al., 2018).

Temperature surrounding must be suitable with crop planted. The temperature needs to be controlled differently when day and night-time. Night temperature must be lower by 3°C to 5°C from daytime temperature sets. Not only that, the different temperature must be adjusted depending on plant season crops. For warm-season crops, they might need a higher temperature than cool-season crops (Table 2.3). If the temperature set below essential needed of the crops planted, it will give effect to the plant growth like less production of fruit or effect on plant colouration (Resh, 2013b).

Table 2.3 Range of temperature for crops according to its season (Resh, 2013b)

Type of season	Suitable range of temperature	Example of crops
Warm season	Day time: 24°C Nighttime: 16°C	Tomatoes.
Cool season	Day time: 16°C to 18°C Nighttime: 13°C	Lettuce and other leafy vegetables

Fan pad cooling system is one of the methods used to circulate the air inside the greenhouse where one side of the wall attached with evaporative cooling pad and the other side mounted with exhaust fan. On the cooling pad, water is circulated while hot air is forced in through the wet pad. When the hot air passing through the wet pad, automatically the air will become cool inside the greenhouse and at the same time relative humidity will be raised. Root cooling system

The air temperature inside the greenhouse may affect root zone temperature during daytime, especially in the tropical region. Root zone temperature plays a big role in giving a high production of crops. In NFT system, it is an important thing to make sure the crop roots in a healthy condition. Roots responsible to absorb nutrient and water for plant growth. Therefore, the root zone should be kept in a range of 15-20°C (Suraidi et al., 2009).

2.3.5 Carbon dioxide (CO₂) enrichment

In a plant factory, carbon dioxide (CO₂) concentration become one of the main factors affecting the absorption rate of the plant. CO₂ controller installed inside the plant factory functioned as to measure the concentration of CO₂. The controller will send a signal to the pneumatic electromagnetic valve to supply the CO₂ when the controller detects a lower concentration of CO₂ than the lower limit that has been set up (Quan et al., 2018).

H. M. Resh (2013a) mentioned that carbon dioxide (CO₂) enrichment used in commercial crop production can raise the yield up to 20%. The optimum level of CO₂ for the most plant is between 800 ppm to 1200 ppm; however, the ambient level of CO₂ is about 300 ppm. The size of the unit system is depending on the area of the plant need to be enriched with CO₂. CO₂ generator needs to be operated using a timer during daytime. It is because the generator will produce excessive heat that will affect the crops. Hence, it is important to use the timer to control the CO₂ using period.

2.3.6 Wall insulation

Maintaining the temperature inside the greenhouse is very important in helping to create a better environment for the plant growth. In order to maintain a temperature, insulating the greenhouse can be used as it may benefit to the energy savings. Injection of liquid foam insulation between two layer of PE film prove that it can save 42 % of energy during night and 50 % energy saving after improvement (Villeneuve et al., 2005).

Meanwhile, zigzag configuration of insulating covering material shows that 90.5% of light transmitted through directly and 80% is diffused. For a better result, double sheet of zigzag configuration using polycarbonate material is used. About 25 % energy can be saved when using a good selection of insulation material (Sonneveld & Swinkels, 2005).

2.4 Crop selection in Nutrient Film Technique (NFT) system

2.4.1 *Lactuca sativa*

Lettuce (*Lactuca sativa*) is a crop planted normally in the most temperate and subtropical region. There are four varieties of lettuce mainly used in NFT planting: Bibb lettuce, loose-leaf lettuce, head lettuce and romaine lettuce. Among these four varieties, Bibb lettuce is the most suitable for hydroponics and controlled environment. While, loose-leaf varieties are the easiest variety to grow as it can tolerate high temperature (Resh, 2013a).

Table 2.4 Lettuce growing requirements

Lettuce requirements	Sources
Germination temperature	15-18°C
Growing temperature	Day: 18- 21°C Night: 13-16°C
Carbon dioxide enrichment	1000 ppm during day
EC	1.5 to 2.0 mS depending upon the light
Relative humidity	60-80%
Optimum pH	5.5 to 6.5
Light level	16 hours of daylight PPFD: 250 $\mu\text{moles/m}^2/\text{s}$

(Resh, 2013a)
(Zhang et al., 2018)

CHAPTER 3 MATERIAL AND METHOD

3.1 Site location

Study on Vertical Nutrient Film Technique (VNFT) for hydroponic planting system was conducted at Padeetech, UPM-MTDC, Universiti Putra Malaysia.

3.2 Materials

All the material listed at Table 3.1 were purchased at D Syira Enterprise (456, jalan 18/2a, Taman Seri Serdang, 43300, Seri Kembangan) and from Shopee.

Table 3.1 Materials for the NFT system

1. UPVC pipe	7. White LED 5 m
2. pH meter	8. T5 tube LED Grow Light 30 cm 6 watt
3. Cube hydroponic sponge	9. Green Lettuce seed
4. Liquid fertilizer A&B	10. Red Lettuce seed
5. PVC solvent cement 100 gm	11. Hydroponic net pot
6. Pipe clip	12. Organic composed soil 1 kg

3.2.1 Bill of quantity (BOQ)

The bill of quantity refers to the number, quantity of items purchased for the construction of the NFT system with per unit costs and total costing (the NFT structure and pump have been constructed):

Table 3.2 Bill of Quantity (BOQ)

No.	Quantity	Items	Per unit cost (RM)	Total cost (RM)
1	1	PVC pipe clear ¾" 3m	2.00	2.00
2	1	pH meter	17	17
3	1	Cube hydroponic sponge	5.80	5.80
4	1	Liquid fertilizer A&B	14	14
5	1	PVC solvent cement 100 gm	3.80	3.80
6	2	Pipe clip	0.90	1.80
7	1	White LED 5m	50	50
8	1 set	T5 Tube LED Grow light 30 cm 6W	67.68	67.68
9	1	Green lettuce seed	2.80	2.80
10	1	Red lettuce seed	2.80	2.80
11	36	Hydroponic net pot	0.20	7.20
12	1	Organic composed soil 1 kg	7.00	7.00
			Grand total	181.88

3.3 Method for determining planting structure

3.3.1 Selection of frame and gully

In selecting a frame, the following criteria need to be considered:

1. High durability
2. Light material
3. Good strength capacity
4. Long-life span

In selecting gully; the following criteria need to be considered:

1. Size and shape gully
2. High rigidity
3. UV stabilised Food Grade PVC or HDPE

3.3.2 Total number of plants

In determining a maximum capacity of plant that can be planted for a structure, the following equation was used:

$$N_p = \frac{\text{Area of planting}}{\text{Planting spacing}} \times \text{no. of trays per structure} \quad (3.1)$$

Where; N_p is total number of plants, Area of planting and planting spacing is in m^2 .

3.3.3 Total load of structures

In determining the total load of structures, the following equations were used:

$$V_t = l \times w \times h \times \text{no. of trays per structure} \quad (3.2)$$

Where; V_t is the volume of tray in m^3 , l is the length of tray (m), w is the width of tray (m), and h is the height of tray (m).

$$M_t = \rho_{tray} \times V_t \quad (3.3)$$

Where; M_t is the mass of tray in kg and ρ_{tray} is 1.38 g/cm³.

$$V_W = l \times w \times h \times \text{no. of trays per structure} \quad (3.4)$$

Where; V_W is the volume of water in m³, l is the length of water (m), w is the width of water (m), and h is the height of water(m).

$$M_W = \rho_{water} \times V_W \quad (3.5)$$

Where; M_W is the mass of water in kg and ρ_{water} is 1 g/cm³.

$$M_P = N_P \times \text{weight of 1 plant} \quad (3.6)$$

Where; M_P is the mass of plant in kg and N_P is the total number of plants.

$$M_T = M_t + M_W + M_P \quad (3.7)$$

Where; M_T is the total mass of tray, water and plant in kg.

3.3.4 Frame analysis

Analysis of frame on axial load, shear diagram and moment diagram will be done using RISA-2D Educational. The drawing of structure must be done inside the RISA and determine the support and load. Then, analysis can be run.

3.4 Method of selection for the pumping system

In determining the suitable pumping system for the structure, it is important to consider the following criteria:

1. Estimation of pump capacity to supply the water in litre per hour (LPH)
2. Head of the pump can pump the water up to the structure height.

3.4.1 Determination of flow rate (Q) using Manning's equation

Calculation on flowrate (Q) using Manning's equation for vertical NFT are carried out as the following equations;

$$\text{area } (A) = b_w \times y \quad (3.8)$$

Where; A is the area of water (m²), b_w is width of base of gully (m), and y is height of water (m).

$$P = b_w + 2y \quad (3.9)$$

Where, P is the perimeter of water (m).

$$\text{hydraulic radius } (R) = \frac{\text{Area } (A)}{\text{Perimeter } (P)} \quad (3.10)$$

Where; R is hydraulic radius (m).

$$\text{velocity, } V = \frac{R^{2/3} \sqrt{S_o}}{n} \quad (3.11)$$

Where, velocity of water, V is in m/min, n is Manning's coefficient with value 0.012-0.017 (Han, 2008). S_o is the channel of the slope of 0.003.

Since $Q=AV$, another form of the Manning's equation is

$$Q = \frac{A^{5/3} \sqrt{S_o}}{nP^{2/3}} \quad (3.12)$$

3.4.2 Pump size determination

Determination of suitable pump size for the VNFT system can be determined using the following equation;

$$\text{required power, } WP = Qph9.81 \quad (3.13)$$

Where; required power, WP is in W, pump discharge, Q in m³/s, ρ is density of liquid (kg/m³).
h is total dynamic height (m) and 9.81 is average intensity of gravity.

3.5 Method for Vertical Nutrient Film Technique (NFT) system

Method for VNFT explained in roughly.

1. Prepare all the material needed, review guide and the layout diagram and prepare the side.
2. Build up the frame and place the tray with slope (%), pipe and fittings.
3. Germinate the crops.
4. Prepare the nutrient solution. Check pH and EC.
5. Prepare the pump.
6. Test the system.

3.6 Method of selection for the lighting system

In the selection of suitable lighting for the NFT system, it is important to follow the following criteria:

1. Type of crop that will be planted. The leafy vegetable may require low light intensity than fruity crops.
2. Plant growth spacing.
3. Electricity output and consumption
4. LED growth life span. Normally provided by manufacturers.
5. Light coverage needed for crops planted.

3.6.1 Lighting system setup for NFT system

Method of the setup of the experimental system of the lighting system of NFT system is as in Table 3.3:

Table 3.3 Setup method of the experimental system of the lighting system for NFT system

a) Setup the pipe from the guppy tank to place the nutrient solution to the NFT pipe, make sure all the system working out.

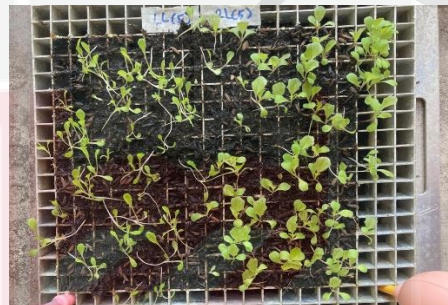
b) Positioned the organic soil into the SRI tray



c) Seeding the green lettuce and red lettuce into the SRI tray prepared



d) The lettuces ready to transplant



e) Prepared the right ratios of nutrient water using liquid fertilizer A&B for the lettuces. Mixed the fertilizer with the clean water inside the guppy tank

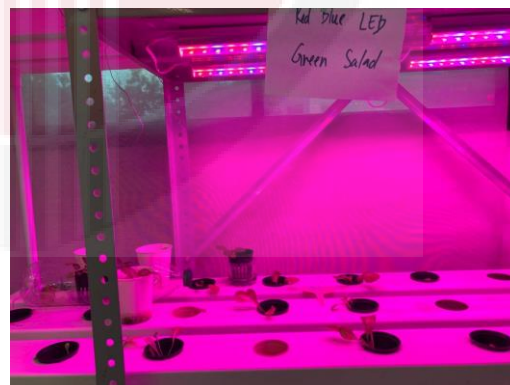
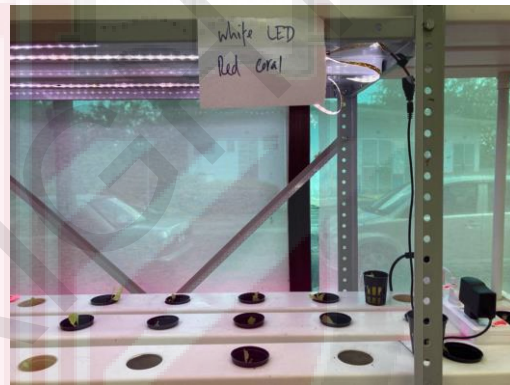
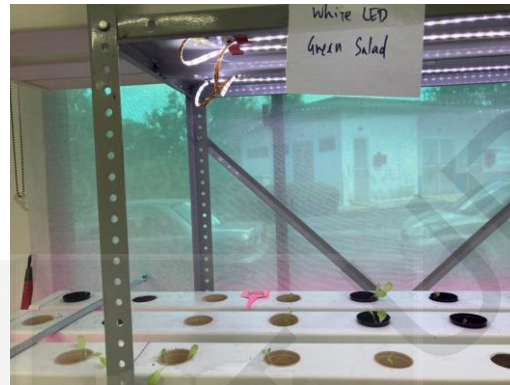
f) Checked the right pH using pH meter.

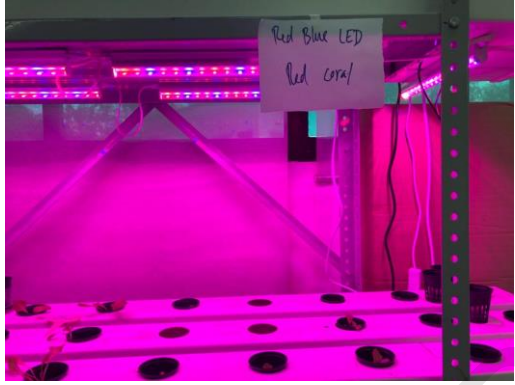


g) Checked the right EC using EC meter.



h) Positioned the lettuce sapling to the NFT system according to its category



	
<p>i) Monitored and measured the height of lettuce, EC, and pH of water inside the guppy tank. Readings taken for 8 days.</p>	

3.7 Suitable fertilizer rate for lettuce

In determining suitable fertilizer for rocket salad and lettuce, different range of pH and EC will be required.

3.7.1 Guideline of seedling mixing

In preparing nutrient solution mixing for lettuce, following guideline has to be followed:

1. Fertilizer A and B should be diluted together with water 10 mL each for 4L of clean water.
2. Take 100 ml of fertilizer A and B and dilute with 40 L of raw water.
3. Blend the mixture until it is perfectly mixed.

3.7.2 Maintenance guide

In NFT systems, it is important to do maintenance to the tank and nutrient solution. Following criteria need to satisfy:

1. Regularly test the pH and EC of water and nutrient solution in the tank. Optimal reading frequent is twice a day or at least once daily. To get a better result, the reading should be taken at the same time daily.
2. Change the water in tanks every couple week or depends can be a few weeks if the water does not evaporate rapidly. Monitor the top off log in tanks, if the water is half than initial volume then it is time to change the water.

3.8 Suitable environment conditions for lettuce

Determining the suitable environment condition for rocket salad and lettuce may be almost in the same range.

3.8.1 Determination of humidity and temperature system

In the application of a fan pad system in the greenhouse, it is important to take the following considerations:

1. System efficiency
2. Greenhouse location and orientation
3. Type of cooling pad
4. Cooling pad area
5. Water flow rate
6. Exhaust fan locations

3.8.1.1 Evaporating cooling system

Calculation of pad requirements are as follows;

$$\text{Standard cmm} = L \times W \times C \quad (3.14)$$

Where; Standard cmm is rate of air exchange under standard condition, L is length of the greenhouse (m), W is width of the greenhouse (m) and C is 2.5 cmm

The rate of air movement is depending on F_{elev} , F_{light} , F_{temp} . Standard rate of air removal can be corrected by multiplying the factors of elevation, light and temperature to get the factor of house.

$$F_{house} = F_{elev} \times F_{light} \times F_{temp} \quad (3.15)$$

Where; F_{house} is factor of house.

Determination of the volume of air to expelled from the greenhouse each minute as follow:

The final capacity of the exhaust fans must be,

$$Total\ cmm = Standard\ cmm \times F_{house} \quad (3.16)$$

Calculation on determining selecting fan as the following:

$$N_F = \frac{l}{7.6\ meter} \quad (3.17)$$

Where; N_F is the number of fans needed, l is length of the wall housing the fans.

$$S_F = \frac{PA}{Nof.\ of\ fan} \quad (3.18)$$

Where; S_F is size of fan in cmm/fan and PA is AF is total airflow requirements for greenhouse in m^3/min

3.8.2 Determination of carbon dioxide (CO₂) system

In the selection of the CO₂ system, it is important to take the following considerations:

1. Amount of CO₂ needed
2. CO₂ enrichment operating hour

3.8.2.1 Amount of CO₂ enrichment needed to raise in greenhouse

Calculation on the amount of CO₂ is carried out as the following equation:

$$\text{Amount of } CO_2 \text{ needed} = \text{Volume of greenhouse} \times \text{desired } CO_2 \text{ level} \quad (3.19)$$

Where; Amount of CO_2 needed is in m^3 , Volume of the greenhouse is in m^3 , and the desired CO_2 level is in ppm.

3.8.3 Suitable wall insulation for the green house

In determining the suitable wall insulation of the greenhouse, the following criteria should be followed:

1. Type of crops that will be planted
2. Size of greenhouse. Larger greenhouse may require a specific type of insulation to trap the heat.
3. Depends on the environment that want to create.

CHAPTER 4 RESULT AND DISCUSSIONS

4.1 Frame structure analysis

The analysis of structure is analysed using RISA 2D. The structure can fit for 1250 total number of plant (Appendix I). The load impose is calculated from weight of water, weight of tray and weight of plants. The calculation for total load acting on each tier was 1.57 kN/m for each tier (Appendix II). The analysis of frame structure must be done to check the stability of the structure. The axial forces acting on the structure illustrated in Figure 4.2 show that the forces become larger as it goes down and the middle bar have a larger forces compared to the other bars. The shear forces explained that the forces pushing at one part of the body and another part of the body will act oppositely. The shape of shear diagram appeared as in the Figure 4.3 due to forces acting on vertically is distributed uniformly. The contra point where the positive shear force shifting to the negative region occurred at 2.5 m and 7.5 m. At these points, the shear force is equal to zero. The moment diagram shown in Figure 4.4 demonstrated a parabolic shape. The maximum bending moment occurred at 2.5 m and 7.5 m where the shear forces intersect at its axis. Since there are no coupling moment occurred at the support, then there are no moment force acting on it.

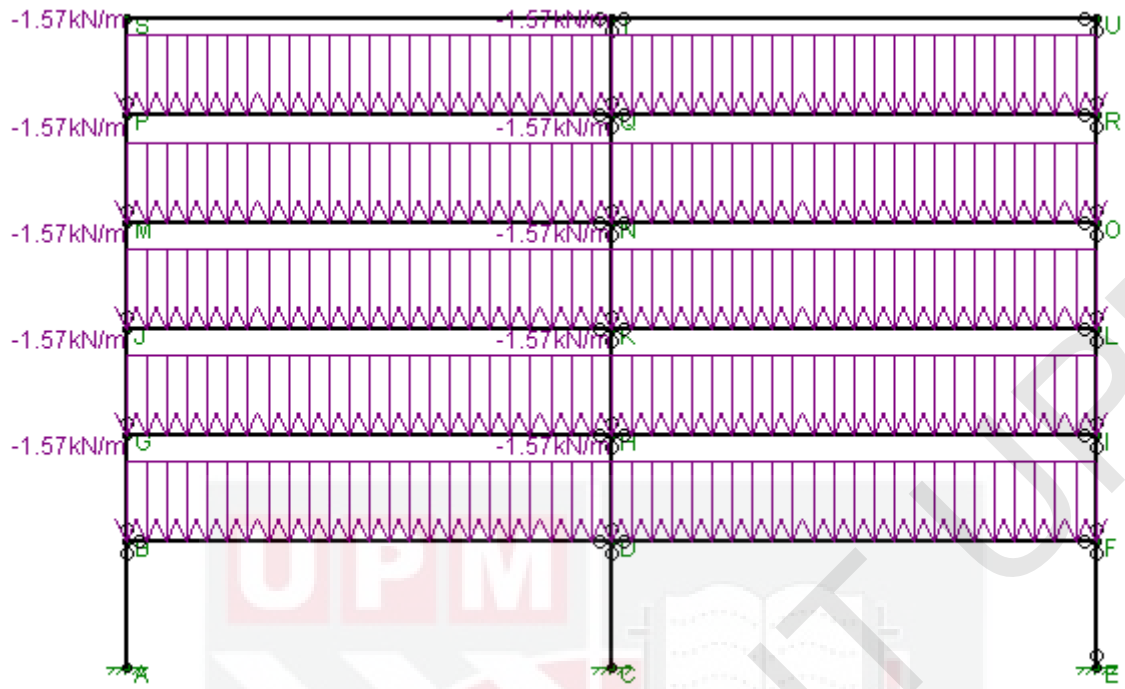


Figure 4.1 Horizontal distribution load acting on each layer is 1.57 kN/m

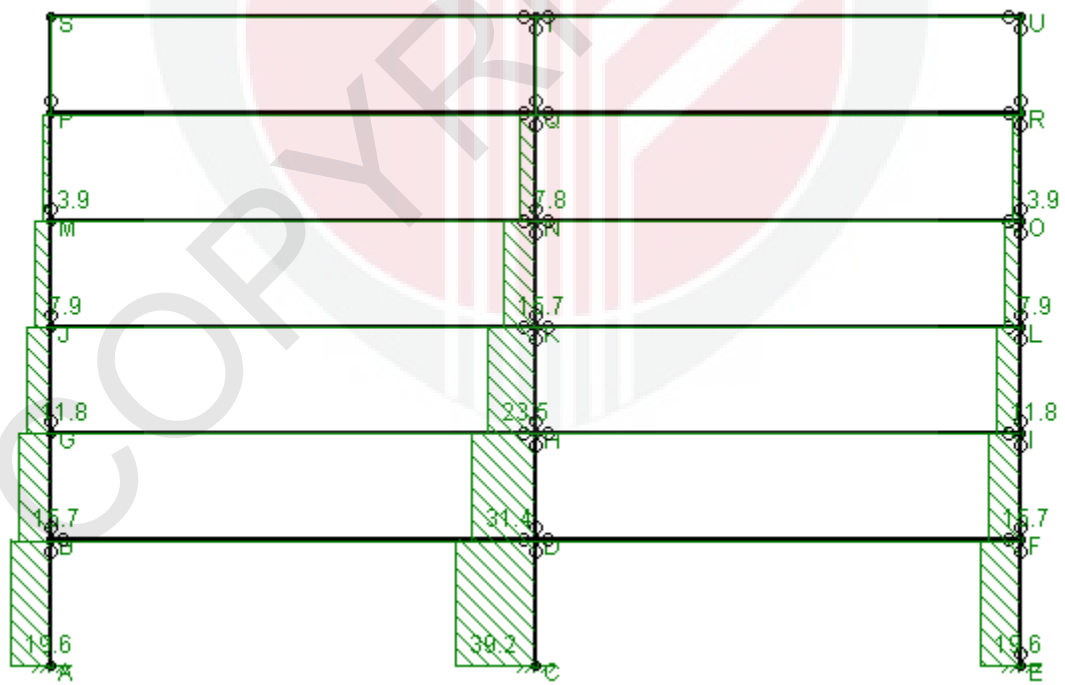


Figure 4.2 Axial forces of the structure

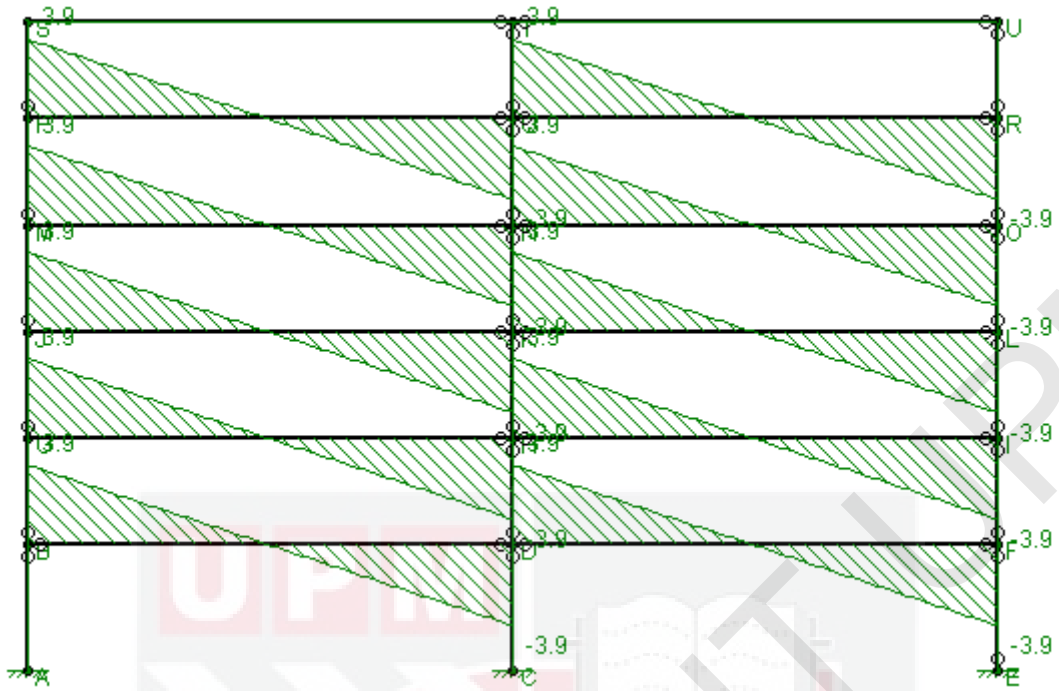


Figure 4.3 Shear forces of the structure

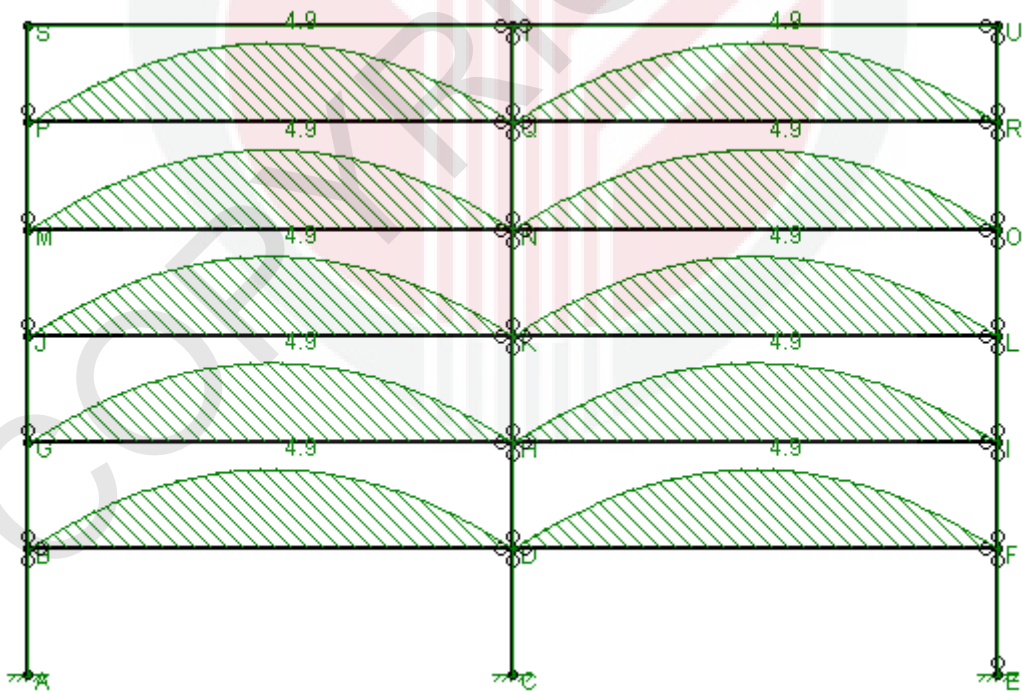


Figure 4.4 Moment diagram of the structure

4.1.1 Schematic design for Nutrient Film Technique (NFT) system

The NFT structure design prepared using Autodesk Inventor Professional 2019 as appeared in Figure 4.5. The structure consisted of 5-tier tray vertically. The dimension of this structure is 10 m x 1 m x 6.7 m (length x width x height). For every 2.5 m starting from the left supported with horizontal beam and vertical beam supported at 5 m from the left. The height between each tier is 1 m to make sure the space for the plant to growth is suitable and to ensure the light is distributed well. The height from ground to the first tier is 1.1m to give a space for guppy tank to be placed. Every tier will be placed with three gullies with size of 10 m x 0.3 m x 0.5 m (length x width x height).

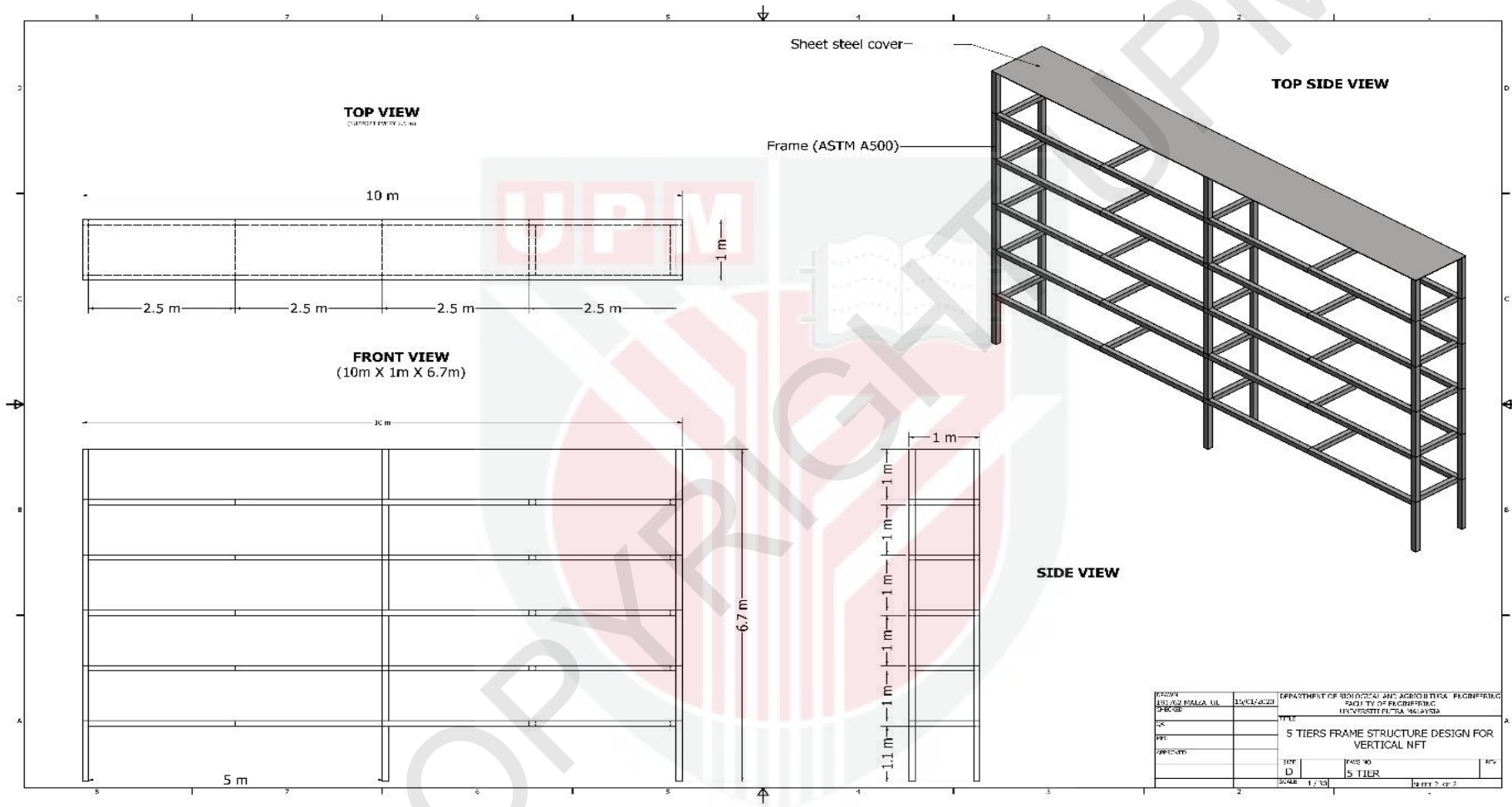


Figure 4.5 Schematic design of Vertical NFT structure

4.2 Flow rate (Q)

In determining the flowrate, the Manning's equation was taken into consideration to calculate the flowrate required inside the Nutrient Film Technique (NFT) system. Using the equation, parameters such as, Area, $A= 6 \times 10^{-3} \text{ m}^2$, the Perimeter, $P= 0.34 \text{ m}$, Hydraulic radius, $R=0.017 \text{ m}$, Velocity, $V= 0.3 \text{ m/min}$, hence from that, the Flowrate, $Q= 108 \text{ L/h}$ for the NFT systems.

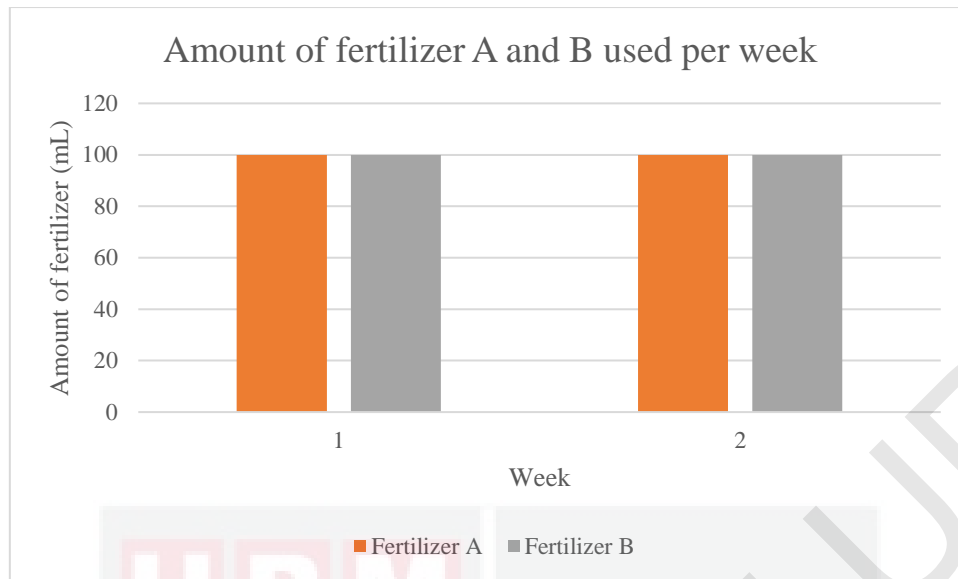
Usually, the recommended flowrate in range of 1 - 2 L/m or 60 - 120 L/hr. The result obtained from the design achieve the recommended flowrate. Details may refer to (Appendix III).

4.2.1 Determination of pump size (P)

From the previous result in 4.2, the flowrate will be used to determine the pump power required to supply the water throughout the system. Given the density of water (ρ) is 1000 kg/m^3 , total dynamic height (h)= 7 m, and average intensity of gravity (g) = 9.81 m/s^2 , pump efficiency of 0.8, thus the pump power (P)= 2.6 watt (0.003 hp). Details may refer to (Appendix III)

4.3 Most suitable fertilizer mixture for Green Lettuce and Red Lettuce

Since the vegetable used comes from the same family of lettuce, the pH and EC range used will be in the same range in determining the most suitable fertilizer mixture rate. Fertilizer nutrient A&B added in weekly as shown in Graph 4.1. both weeks will be added around 100 mL of fertilizer A and B into the raw water of 40 L.

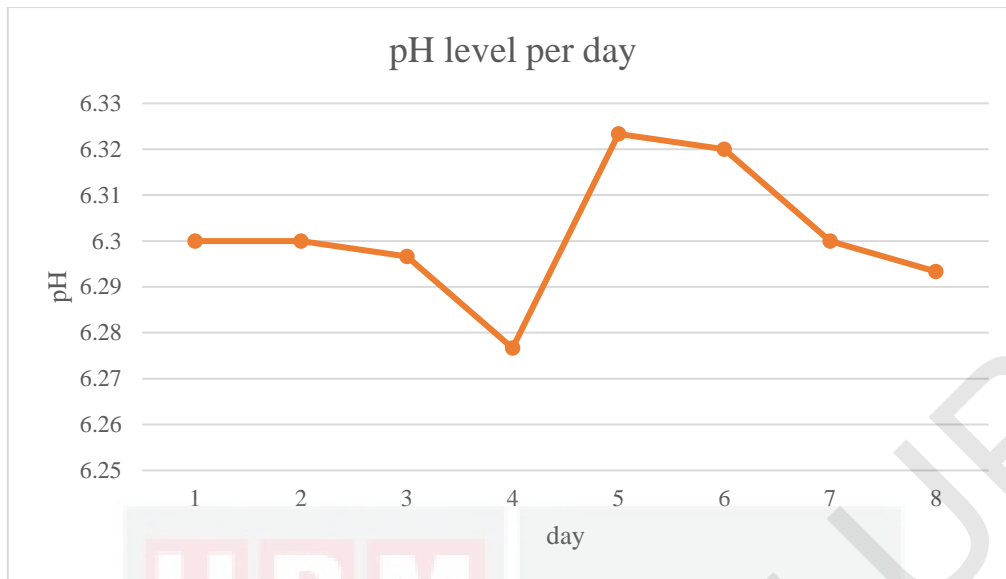


Graph 4.1 Graph of the amount of fertilizer A&B per week

4.3.1 pH level for Green Lettuce and Red Lettuce

pH level may vary depending on different plants growth. It is required to measure the pH of nutrient solution to see the changes of reading. The changes of pH show the nutrient availability in the solution.

The pH level maintained according to the plant growth stage requirement, where lettuce prefer a pH range of 5.5 to 6.5 (Resh, 2013a). Demonstrated in Graph 4.2 predicted of optimum pH of about 6.32.

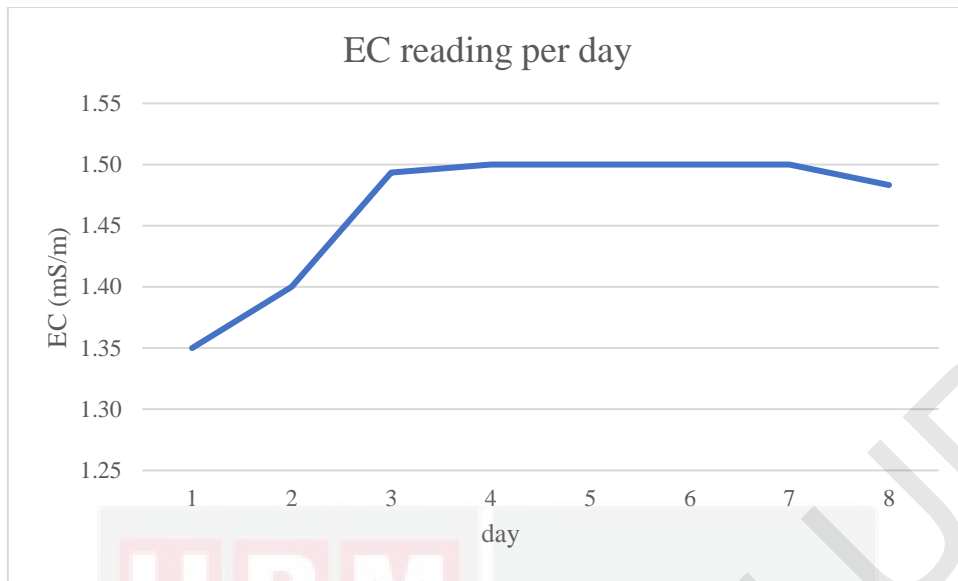


Graph 4.2 Graph of pH level per day

4.3.2 EC reading for Green Lettuce and Red Lettuce

EC level will differ according to plant type and its growth stage. The EC meter taken was stable at 25°C of surrounding temperature to have an accurate reading. For lettuce, the EC level should be in range of 1.5-2.0 mS/m (Resh, 2013a)

The EC level maintained between in range of lettuce suitability every day. Shown in Graph 4.3, the predicted an optimum EC value about 1.6 mS/m.



Graph 4.3 Graph of EC reading per day

4.4 The need of suitable lighting for the NFT system

4.4.1 Lux meter

The lux reading was taken using lux sensor meter as in Figure 4.6 and Figure 4.7. From Table 4.1 show the average lux of white and red blue led attached 0.9 m from the upper surface of tray. The average reading of lux for red blue LED is higher than the white LED which affect the height difference of lettuce planted under both LED. However, the recommended lux for lettuce in range of 1438-1442 lux (Promratrak, 2017).



Figure 4.6 Lux meter sensor to measure white LED lux



Figure 4.7 Lux meter sensor to measure red blue LED lux

Table 4.1 Reading of lux under different type of LED

Type of LED	Reading (lux)			
	1	2	3	Avg
White	111	111	112	111.22
Red blue	293	290	289	290.67

4.4.2 ANOVA and Mean comparison of Green Lettuce

Through the one-way ANOVA, Mean comparison, and SPSS plant height variations within two different type of LED (white and red-blue LED). From Table 4.2 show the mean and standard deviation of green lettuce height under different type of LED (white and red blue). From Table 4.3 illustrate between groups and within groups are not significant which denote a sig. of 0.685 meaning that it is not significant at $p > 0.05$. Since the result is not significant, the post hoc test should not be carried out.

Table 4.2 Appearing the descriptives statistic for green lettuce

Descriptives								
Height (cm)								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
white	72	59.1306	20.89743	2.46279	54.2199	64.0412	17.87	83.20
red blue	72	60.4329	17.41585	2.05248	56.3403	64.5254	36.67	91.83
Total	144	59.7817	19.17933	1.59828	56.6224	62.9410	17.87	91.83

Table 4.3 One way measure analysis of variance of height of green lettuce in vertical NFT systems. The results compare between factors of white LED and red blue LED.

ANOVA					
Height (cm)					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	61.057	1	61.057	.165	.685
Within Groups	52541.032	142	370.007		
Total	52602.089	143			

4.4.3 ANOVA and Mean comparison of Red Lettuce

Through the one-way ANOVA, Mean comparison, and SPSS plant height variations within two different type of LED (white and red-blue LED). From Table 4.4 show the mean and standard deviation of green lettuce height under different type of LED (white and red blue). From Table 4.5 illustrate between groups and within groups are not significant which denote a sig. of 0.467 meaning that it is not significance at $p > 0.05$. Since the result is not significant, the post hoc test should not be carried out.

Table 4.4 Appearing the descriptives statistic for red lettuce

Descriptives								
Height (cm)								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
white	72	40.2292	12.30293	1.44991	37.3381	43.1202	25.87	64.67
red blue	72	41.3810	5.30781	.62553	40.1337	42.6283	25.97	52.70
Total	144	40.8051	9.45906	.78825	39.2470	42.3632	25.87	64.67

Table 4.5 One way measure analysis of variance of height of red lettuce in vertical NFT systems. The results compare between factors of white LED and red blue LED.

ANOVA					
Height (cm)					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	47.763	1	47.763	.532	.467
Within Groups	12746.988	142	89.768		
Total	12794.752	143			

4.5 Evaporative cooling system

The determination of evaporative cooling system for a greenhouse must take the dimension of greenhouse into account. The assumption was made to installed fan in a row located 6 m from the entrance door. The value of air to move per minute under standard condition was 210 cmm with house factor of 1.12. While the volume of air to be expelled from the greenhouse each minute was 235.2 cmm. This is means 235.22 cmm is the final capacity of the exhaust fan needed. The number of fans needed in the greenhouse is 1 with the size of 235.2 cmm for a fan. (Details may refer to Appendix IV)

4.6 CO₂ enrichment in the greenhouse

In a greenhouse, the CO₂ enrichment is important to enhance the lettuce growth. The lettuce need 1000 ppm of CO₂ where the ambient CO₂ was 300 ppm (Resh, 2013b). The amount of CO₂ needed in a greenhouse is 588 000 m³ by considering the volume of greenhouse and desired of CO₂ level. (Details may refer to Appendix V)

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

During the design planning of the planting system for Vertical NFT, a 5-tier of vertical NFT was put into thought with the dimension of 10 m length, 1 m width and 6.7 m height. The tray designed with the dimension of 10 m length, 1 m width and 0.1 m height. For each tier of gully can be planted for 250 plants with 0.2 m by 0.2 m plant spacing, where the overall plant can put for a structure about 1250 plants. The overall load of the structure about 9380.19 kg with the summation of weight of water, tray, plants, and frame. The size of frame selected in this calculation is ASTM A500 (100mmx100mm). In every tier, the load will be distributed for 1.57 kg/N vertically. The analysis of frame was done using RISA 2D by analysed the shear and moment acting on the cross section of the bar.

The area attained for the gully was $6 \times 10^{-3} \text{ m}^2$, perimeter was 0.34 m, hydraulic radius was 0.017 m, velocity was 0.03 m/min. From these data, the flowrate determined using Manning's equation was 108 L/hr as in recommended range.

Considering the pump efficiency of 0.8, manning's coefficient was 0.012, bed slope of 0.003, total head of 7 m, and density of fluid was 1000 kg/m^3 , hence the pump power suitable for the structure was 2.6 watts.

The addition of fertilizer was made at beginning of experiment where 40 L of clean water were mixed with 100 mL of fertilizer A and 100 mL of fertilizer B. After 4 days, the nutrient water was cleaned up and changed into a new nutrient fertilizer with same amount as in the beginning.

The EC and pH level were taken daily using EC meter and pH meter relatively. As the result, the optimum pH was 6.32 and optimum EC was 1.5 mS/m.

The lux sensor meter was used to determine the lux of white and red blue led, where the average lux of white led 111.22 lux was and red blue was 290.67 lux.

The result for One-way ANOVA analysis shows that there is no significance result between height of green and red lettuce under different types of LED which, white and red blue LED. Hence, the height of green and red lettuces not affected by type of LED used.

5.2 Recommendation

To get a better result, it is recommended to run the experiment until harvest stage where the effect of different LED to the plant can be determined in terms of height, weight, and chlorophyll content. Other than that, it is recommended to make some adjustment and addition of LED to get enough light from the LED to improve the plant growth.

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APPENDICES

Appendix I: Determination of total number of plants

The total number of plants determined using equation (3.1):

$$N_p = \frac{\text{Area of planting}}{\text{Planting spacing}} \times \text{no. of trays per structure}$$

$$\text{Area of planting} = 10m \times 1m = 10m$$

$$\text{Planting spacing} = 0.2m \times 0.2m = 0.04m$$

$$N_p = \frac{10m}{0.04m} \times 5 = 1250 \text{ plants/structure}$$

Appendix II: Determination of total load structure

Volume of tray,

$$V_t = l \times w \times h \times \text{no. of trays per structure}$$

$$= 10m \times 1m \times 0.1m = 1m^3$$

Weight of tray,

$$W_t = \rho_{\text{tray}} \times V_t = 1.38 \times 1 \times 1000 \times 5 = 6900 \text{ kg}$$

Volume of water,

$$V_w = l \times w \times h \times \text{no. of trays per structure} = 10 \times 1 \times 0.1 \times 5 = 1m^3$$

Weight of water,

$$W_w = \rho_{\text{water}} \times V_w = 1000 \times 1 = 1000 \text{ kg}$$

Weight of plant,

$$W_p = N_p \times \text{weight of 1 plant} = 250 \times 0.3 = 75 \text{ kg} \times 5 \text{ trays} = 375 \text{ kg}$$

Weight of frame equal to 1480.19 kg

Total weight,

$$W_T = W_t + W_w + W_p + \text{Weight of frame} = 9380.19 \text{ kg}$$

Appendix III: Determination of flow rate and pump size

Calculation of Area,

$$\text{area } (A) = b_w \times y = 0.3 \times 0.02 = 6 \times 10^{-3} \text{ m}^2$$

Wetted perimeter,

$$P = b_w + 2y = 0.3 + 2(0.02) = 0.34 \text{ m}$$

Hydraulic radius,

$$\text{hydraulic radius } (R) = \frac{\text{Area } (A)}{\text{Perimeter } (P)} = \frac{6 \times 10^{-3}}{0.34} = 0.017 \text{ m}$$

Velocity,

$$\text{velocity, } V = \frac{R^{2/3} \sqrt{S_o}}{n} = \frac{0.017^{2/3} \sqrt{0.003}}{0.012} = 0.3 \text{ m/min}$$

Flowrate,

$$Q = \frac{A^{5/3} \sqrt{S_o}}{nP^{2/3}} = AV = 6 \times 10^{-3} \times 0.3 = 1.8 \times 10^{-3} \text{ m}^3/\text{min} = 3 \times 10^{-5} \text{ m}^3/\text{s} = 108 \text{ l/h}$$

Pump size,

$$\begin{aligned} \text{required power, } P &= Q\rho h 9.81 = (3 \times 10^{-5})(1000)(7.0)(9.81) \\ &= 2.06 \text{ watt}/0.8 = 2.6 \text{ watt } (0.003 \text{ hp}) \end{aligned}$$

Appendix IV: Calculation involved in the design of evaporative cooling system

Dimension of greenhouse expected to be:

$$\text{Length, } L = 12m$$

$$\text{Width, } W = 7m$$

$$\text{Height, } H = 10m$$

Determination of air to move per minute under standard condition:

Assumed that fan installed in 1 row and located 6m from the entrance door. In standard,
 $C = 2.5 \text{ cmm}$.

$$\text{Standard cmm} = L \times W \times C = 12m \times 7m \times 2.5m = 210 \text{ cmm}$$

$$\text{Given; } F_{elev} = 1.12, F_{temp} = 1.0, F_{light} = 1.0$$

$$F_{house} = 1.12 \times 1.0 \times 1.0 = 1.12$$

Determination of the volume of air to be expelled from the greenhouse each minute:

The final capacity of the exhaust fan,

$$\text{Total cmm} = \text{Standard cmm} \times F_{house} = 210 \text{ cmm} \times 1.12 = 235.2 \text{ cmm}$$

Determination of the number of fans needed,

$$\text{no. of fans} = l/7.5m = 7m/7.6m = 0.92 \approx 1 \text{ fan}$$

Determination of size of fans needed,

$$\text{size of fan} = \text{Total cmm}/\text{no. of fans} = 235.2/1 = 235.2 \text{ cmm}/\text{fan}$$

Appendix IV: CO₂ enrichment in the greenhouse

Determination of CO₂ needed in greenhouse,

Amount of CO₂ needed = Volume of greenhouse × desired CO₂ level

$$= 840 \text{ m}^3 \times 700 \text{ ppm} = 588\,000 \text{ m}^3$$

