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Design and Development of Automated Indoor Farming with Alert System

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ABSTRACT

Indoor farming is becoming an addition to conventional farming practices. This project focused on designing a new, multilevel automated aeroponics system. This newly designed prototype includes an alert system that can alert the user at low water tank levels. The proposed multilevel aeroponic was tested for suitability for maximum plant growth configurations. The prototype development consists of several phases: primary structure, plastic container, water piping, and system setup. Various experiments were conducted within five weeks. The configurations involve changing lighting hours and irrigation patterns. The project's outcome shows the configuration with 12 hours of lighting and a 20-minute misting cycle provides maximum growth. A few recommendations such as lightning setup, user control and misting cycle were also discussed.

1. Introduction

It is estimated that by 2100, the population of human beings will reach 11.2 billion, which will give rise to high demand for food supply [1]. This translates to increased demand for food in future years and thus the need for new agricultural practices and advancements that can increase food production. The conventional method of farming crops using land pesticides and fertilisers to date is still the main farming practice. This traditional farming practice also faces labour scarcity worldwide farms [2]. Growing food for the increasing population throughout the years also faces many problems in terms of land area, effect on nature and shortage of supply. The land available for farming continues to shrink as the city expands. This distance between the farming area and the city will also increase transportation expenses to transport grown food to the city. The time required to transport the food will also affect the freshness of the grown food.

Apart from facing the shortage of land for agricultural purposes, the agriculture sector also faced socio-economical obstacles such as labour shortage. Various studies and reports have identified labour as one of the issues in traditional farming [3,4]. Changes in the government policies and low wages offered to the labour are also identified as issues affecting the agriculture industry [5].

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Water also plays an essential role in agriculture. In the Malaysian agriculture industry context, water usage has also reached the limit of sustainability as the Water Sustainability Index (WSI) in Malaysia dropped to 33% in 2002 from 64% in 1992. This shows that Malaysia's water resources are rapidly decreasing and not appropriately maintained, causing inadequate clean water sources in the future [6].

To meet the growing demand for future population and water sustainability in agriculture, a new evolution of growing and harvesting produce practice known as urban farming has gained popularity. This is a green and self-sustaining initiative. There are many urban farming strategies available and currently applied. Vertical farming is one such strategy that is on its way to becoming an addition to conventional agricultural practices [7].

Aeroponic is one of the urban farming methodologies applicable. This method reduces water usage, fertiliser, soil and space [8,9]. Aeroponic is a soilless method where the crop is suspended in the air, and a sprinkle of water and nutrients is applied to the roots of the crops. Botanists developed the technique in the 1920s by botanists to study the root structure [10]. This method would require spray, mister fogger or any other device that can produce fine mist [11]. Applications of aeroponics to produce vegetables have been reported and researched in the past by researchers around the world using various tools; thus, it is an up-and-coming method to overcome the food shortage [12-16]. On top of that, the incorporation of IoT into agriculture purpose has been adopted by researchers focusing on soil-based plant cultivation [17].

In the Malaysian context, the agricultural industry faces the same issue, such as reducing the land area for agriculture purposes, and the demand for food has increased over the years. Figure 1 illustrates the amount of fruit and vegetables imported from the Ministry of Agriculture and Agro-based Industry. The data indicated that the imported vegetable increased from 1,301,467 metric tonnes in 2009 to 1,391,285 metric tonnes in 2012, and the imported fruits increased from 593,026 metric tonnes in 2009 to 730842 metric tonnes in 2012 [18].

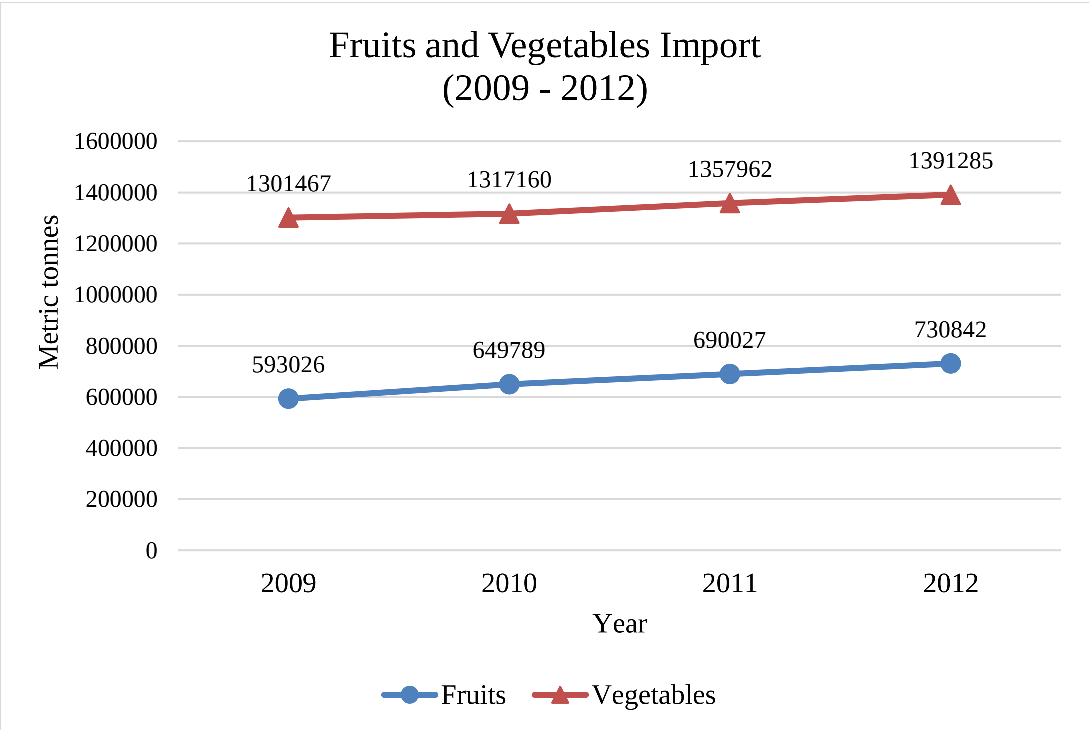


Fig. 1. Import of Fruits and Vegetables for Malaysia from 2009 to 2012

The issues faced by the local agriculture industry warrant the need for research and development to design and develop new strategies to improve food production using vertical farming. This research focuses on the design, innovation and development of an automated aeroponic system. The new prototype will be multilevel, space-saving, lightweight and easy to assemble.

2. Methodology

The design requirement of the prototype can be broken down into three major components, namely structural system, automated system and irrigation.

2.1 Automated System

The automated system developed applied two microcontrollers, the Arduino Mega and NodeMCU. Light intensity sensor, temperature sensor, humidity sensor, and ultrasonic sensor were employed in the prototype. The readings captured by the sensors for the water level detection are connected to Arduino Mega. These values are then transferred serially to NodeMCU for uploading the sensor data to the Blynk application. The user will receive a notification from the Blynk application whenever the water level is less than 25%. The Arduino also controls the operation of the LED and Pump. The pump applied in this project is a 60 W micropump capable of transporting water with a maximum pressure of 80 psi which is crucial to producing a slight mist from the nozzle. Figure 2 illustrates the automated system's working principle applied in the prototype designed and developed.

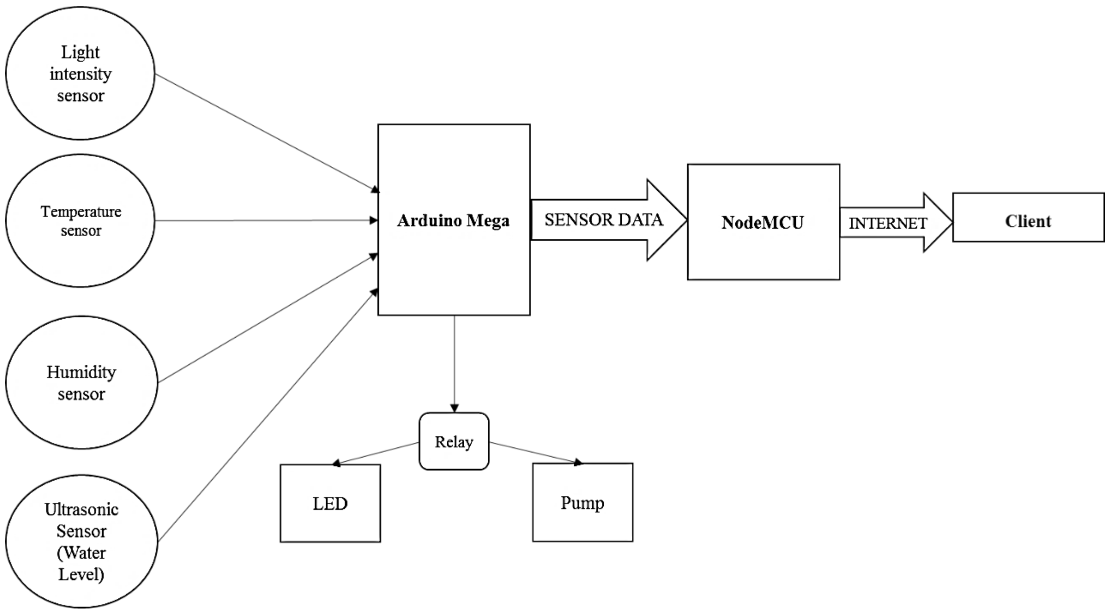


Fig. 2. Working principle of automated system

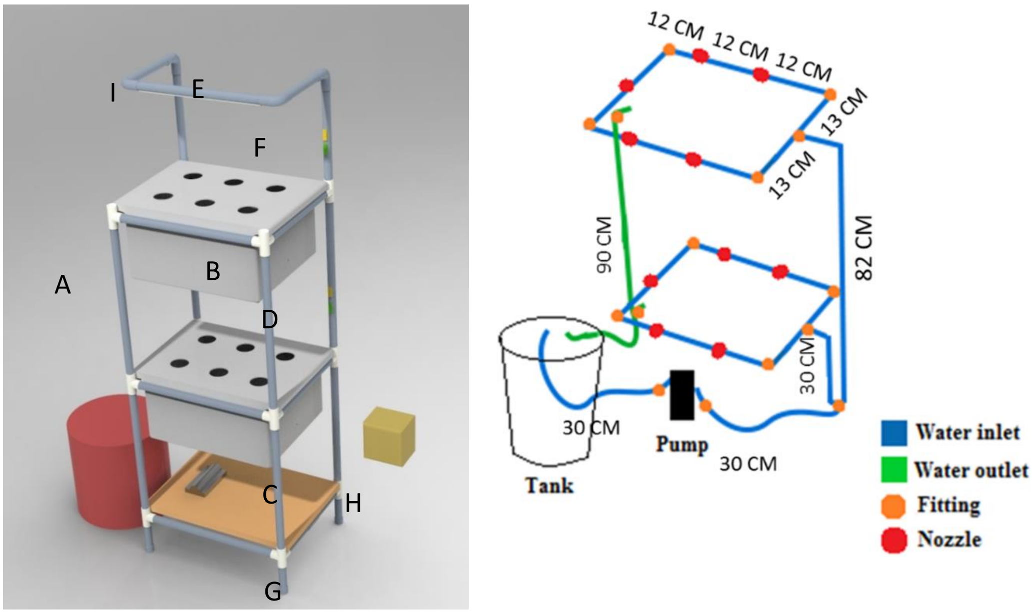
2.2 Structural and Irrigation System

The structural and irrigation system are the heart of vertical farming. As the irrigation system will be based on a variation of hydroponic known as aeroponics, which will deliver the nutrient solutions in the form of a mist directly to the root, the design must ensure that all the seeding will receive a sufficient amount of nutrient solution and illumination.

The multilevel design can accommodate 12 plants at the same time. Eighty per cent of this prototype is made of PVC pipes, and the dimension is illustrated in Table 1 and Figure 3. This PVC part is joint using several fittings to form a multilevel structure. This structure will then support plastic containers, LED, base plate, and sensor placement. Each level includes two LED strips to provide lighting to the plants. The bottom plate in this prototype is designed for pump and extra tubing placement. The electronic box and tank placement are at the right and left sides of the prototype structure. The rationale for this placement is to avoid electronic parts exposed to water in case of water burst or spillage.

Table 1
Dimension of PVC Pipe

PVC structure part	Length (cm)
A	42
B	32
C	42
D	47
E	18
F	27
G	10
H	14.3
I	38



(a) (b)

Fig. 3. (a) Prototype design, and (b) Tubing setup of prototype

Stress and strain analysis is conducted to analyse the impact of the force on the structure. The stress and strain analysis are performed using Creo 5.0 parametric. Table 2 shows the mechanical properties of the main structure and plastic container. The load parameter is shown in Table 3. The load consists of a plastic container comprised of a maximum weight of six plants with an extra 2 kg of load added to simulate stagnant water in case of water blockage.

Meanwhile, the load is applied to the main structure's side support and base where the pump is placed. The side support load is applied according to the load transferred from a plastic container. The baseload is 5.60 kg consisting of 0.6 kg of pump weight and 5 kg extra load for future proof.

Table 2
Mechanical properties of parts in prototype [18,19]

Part	Material	Tensile strength (MPa)
Main Structure	uPVC	55.00
Plastic container	Polypropylene	31.03

Table 3
Load parameters in stress and strain analysis

Location		Load (kg)
Plastic container		6.32
Main structure	Side support	6.32
	Base	5.60

Pump pressure analysis is conducted to ensure the pump can generate more than 80PSI throughout the pipe network to provide fine mist from the nozzle. The investigation is conducted using Pumpsim 3.0 software. The parameter used in the software is shown in Table 4.

Table 4
Parameters used for pump pressure analysis

Parameter		Value
Pump power		60 W
Nozzle flow rate		0.03 l/s
Tube size	Inner diameter	4 mm
	Outer diameter	6 mm

3. Results
3.1 Stress and Strain Analysis
3.1.1 Plastic container analysis

A load is applied on the edge of the holes to simulate the weight of the plant. A two-kilogram load was also applied at the bottom surface of the plastic container to simulate water weight in case of drain blockage. The stress generated by the load is concentrated at the edge of the hole and the bottom of the plastic container. The stress and strain diagram generated is shown in Figure 4. The maximum stress generated is only 0.74 MPa. However, plastic containers are polypropylene plastic, known for their elastic properties. Hence, a little flex from the plastic container cover should be expected. Finally, the container can hold 6.32 kg with a safety factor of more than two.

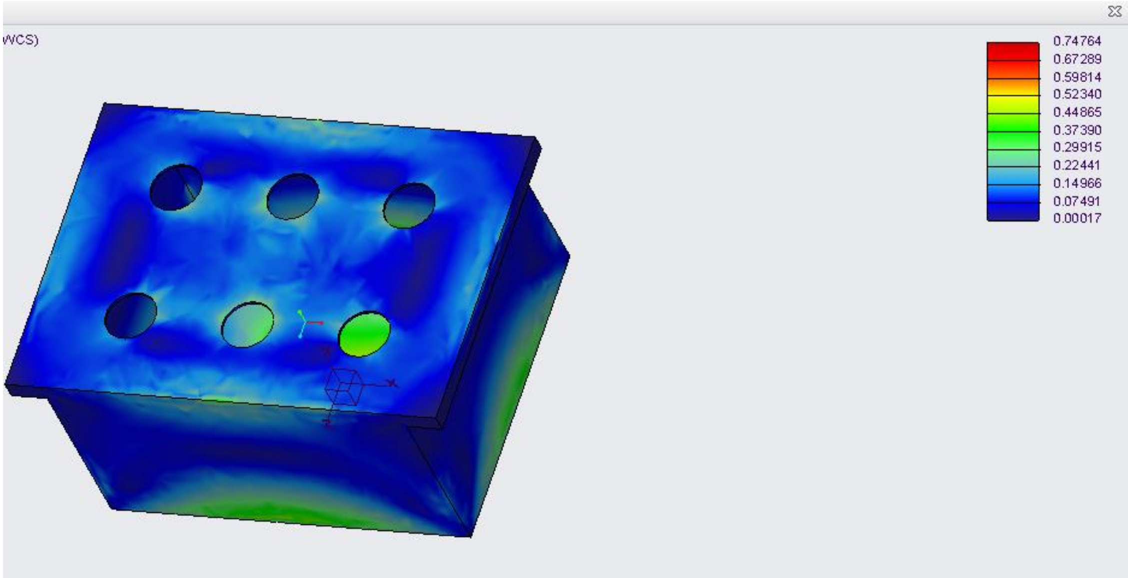


Fig. 4. Stress analysis of plastic container

3.1.2 Main structure analysis

The load was applied on both sides of the main structure that supported the plastic container and at the bottom part of the structure. The stress and strain diagram shown in Figure 5 tells the stress caused by the load is concentrated at the side of the structure and the bottom part of the main structure. The maximum generated stress is 2.305 MPa, giving a safety factor of more than two.

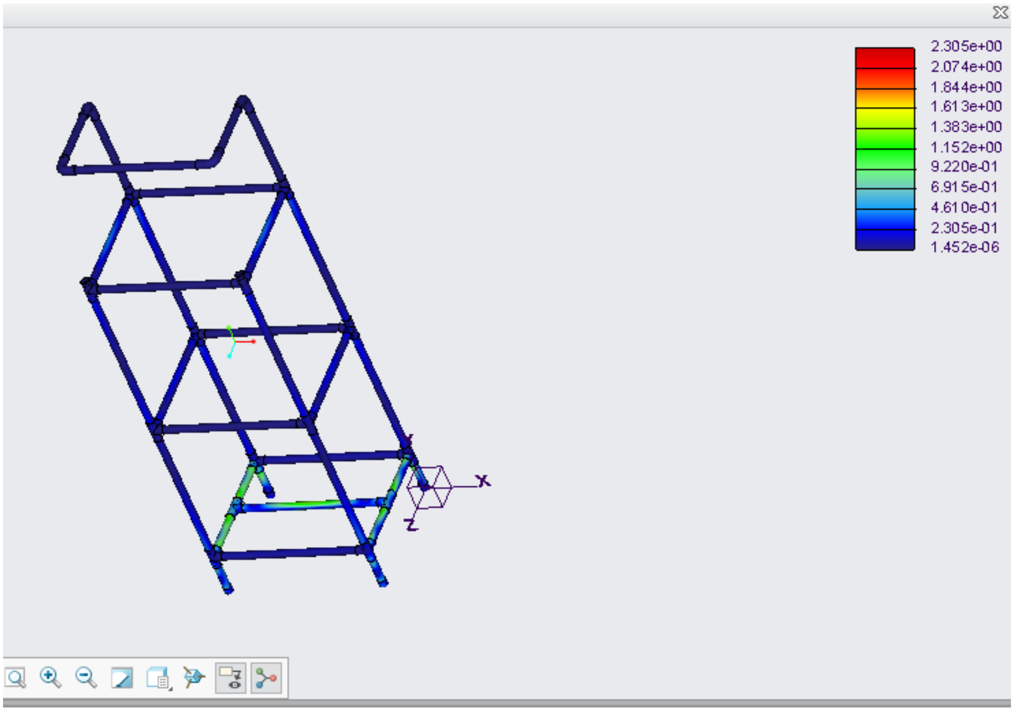


Fig. 5. Stress analysis of structure

3.2 Plant Growth Analyses

Lettuce was used as the plant for the experiment, with lighting provided for 12 hours. Few experiment setup configurations were employed during the project implementation. Configuration 1 was designed with 15-second irrigation every 20 minutes, while Configuration 2 was designed with 15-second irrigation every 30 minutes.

3.2.1 Configuration 1

The data on five-week plant growth from configuration one is shown in Table 5 and plotted in Figure 6. Configuration 1 uses an irrigation pattern of 15 seconds for every 20 minutes and 12 hours of illumination. The starting leaf length of Plant 1 and Plant 2 in this configuration is 0.3 cm. Leaf length continues to grow for Plant 1 and Plant 2 to 1.1 cm and 1.2 cm in week 2. In week 5, Plant 1 and 2 reach 3.3 cm and 3.5 cm, respectively. The average growth for this configuration throughout five weeks is 3.1 cm.

Table 5
Plant growth records for Configuration 1

		Number of leaves		Leaves length (cm)	
	Plant No	1	2	1	2
Week	1	2	2	0.3	0.3
	2	2	2	1.1	1.2
	3	3	3	2.0	2.2
	4	3	3	2.5	2.6
	5	4	4	3.3	3.5

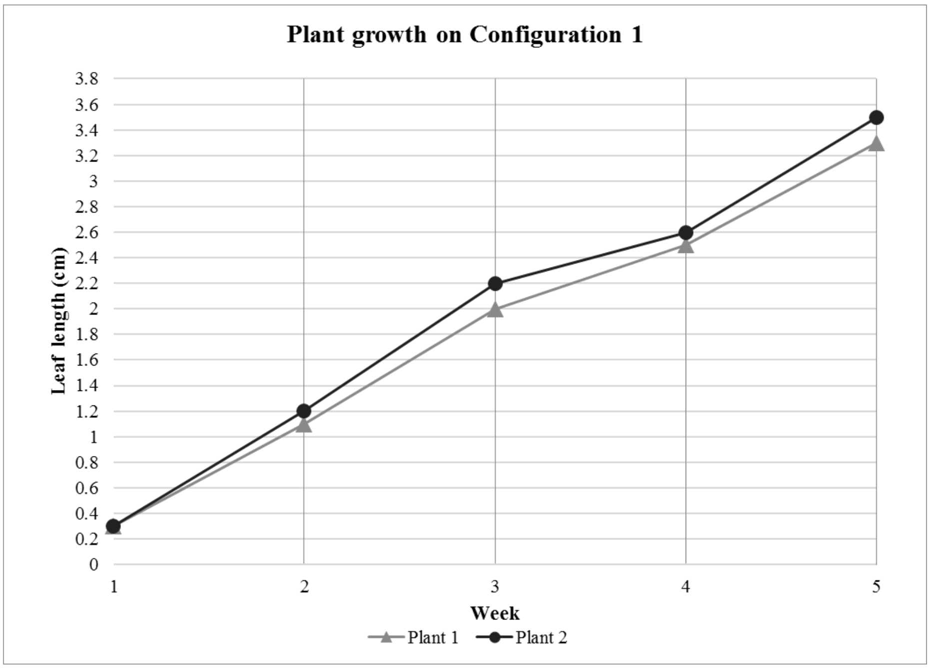


Fig. 6. Configuration 1 plant growth

3.2.2 Configuration 2

Table 6 shows data on leaves length in configuration 2. The data is also plotted in Figure 7. This configuration irrigation pattern was set to be 15 seconds for every 30 minutes, and its lighting hours are 12 hours. The plant starts with different leaf length, where Plant 1 begin at 0.3 cm while Plant 2 begin at 0.2 cm. This extra starting length is probably due to conditions during seed germination, whether moisture level, planting depth or light intensity. Plant 1 reached 3.3 cm in the final week, and Plant 2 reached 3.0 cm of leaf length. The average growth using configuration 2 is 2.9 cm, slightly lower than configuration 1.

Table 6
Plant Growth Records for Configuration 2

		Number of leaves		Leaves length (cm)	
	Plant No	1	2	1	2
Week	1	2	2	0.3	0.2
	2	3	3	1.0	1.0
	3	3	3	2.0	2.0
	4	4	3	2.6	2.5
	5	4	4	3.3	3.0

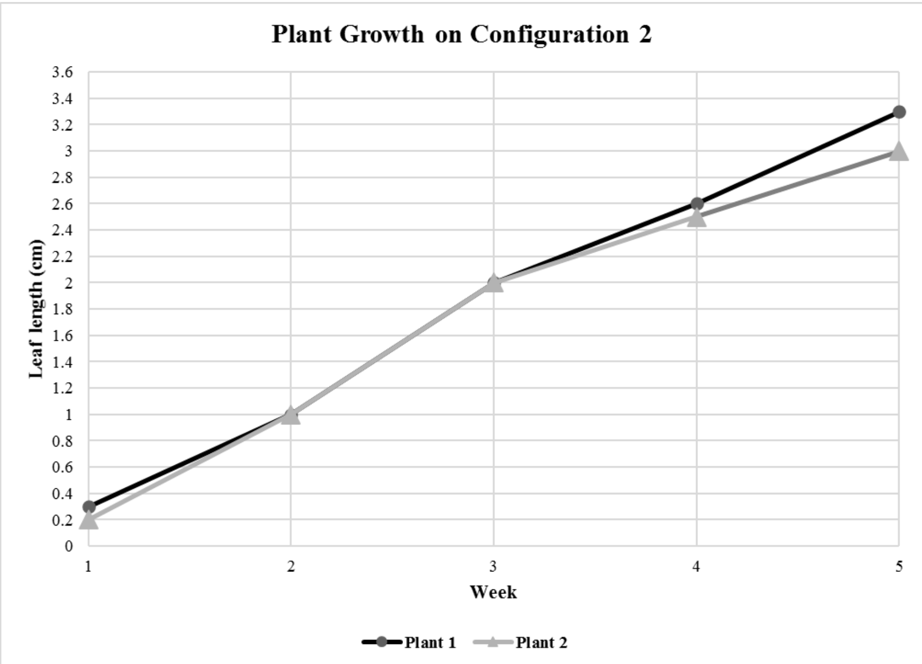


Fig. 7. Configuration 2 plant growth

The possible cause of lower growth is probably due to a lower misting cycle than configuration 1. Configuration 1 was irrigated every 20 minutes, while configuration two was irrigated every 30 minutes. The results yield the same result as the study conducted by researchers from China who implemented different misting cycles in potatoes production using aeroponics. The research concludes that the higher the misting cycle time, the lower the plant yield [20]. Even though there is only a tiny difference in plant growth, it also depends on the surrounding temperature and humidity, which cause the water evaporation rate from the rots, sponge, and plant to increase or decrease.

4. Conclusions

The paper reported on designing a multilevel, automated aeroponic system for vegetable planting systems. With the new design, vertical farming is adopted to maximise land usage for more product output. The results show that for the same type of plant, total lighting of 12 hours with irrigation provided every 20 minutes encourages better plant growth. Such results can be further developed to control the amount of lighting and irrigation patterns to ensure that the plants are in an optimum growing condition with sufficient lighting and humidity.

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