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Design and evaluation of vertical coriander growing equipment using soilless planting media combined with artificial lighting

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Abstract

This research aims to increase the planting area in a 6x24 m greenhouse using a vertical planting system using soilless planting materials combined with artificial light. The vertical planting system will increase the yield per area, grams per plant by designing the planting equipment as an A-Frame layer with 10 planting trays in total. Each tray uses soilless planting materials by experimenting to find the appropriate ratio. Then, the yield from 3 planting methods were compared: A-Frame without light bulbs, A-Frame with light bulbs and a planting table. The results of the experiment to find the planting material ratio found that the ratio that gave the highest yield was coconut husks: raw rice husks: black rice husks: cow dung in a ratio of 2.0:3.0:3.0:2.0, giving an average yield of up to 101 grams/plant. The results of the comparison of the 3 planting methods showed that planting on the A-Frame without light bulbs gave the highest yield per greenhouse, 15% higher than planting on a normal table, which resulted in more cost-effectiveness of using the greenhouse.

Keywords: Vertical farming, Artificial lighting, Soilless cultivation

1. Introduction

Indoor planting in Thailand is becoming more popular, whether it is among those who grow high-priced plants, those who grow plants from abroad, or farmers who want to grow plants out of season. This is because indoor planting has the advantage of being able to control the environment to suit the type of plant being grown. However, greenhouses have higher planting costs than conventional planting. Plants that are grown in greenhouses must be selected to provide worthwhile returns. Coriander is an economic plant with a high price that fluctuates with the seasons. This is because market demand is high but production is limited. In the rainy season, when cultivation is difficult, prices can rise to 200 Baht/kg. In the summer, when cultivation is easier, prices are around 150 Baht/kg. This price difference affects farmers' incomes and makes coriander cultivation a profitable occupation if there is proper management [1]. Coriander grown during the rainy season is at risk of disease and high humidity, so it is suitable for growing in greenhouses to control the environment appropriately. In addition, using a vertical planting system in greenhouses will increase production per area, reduce resource use, and allow coriander to be grown all year round, even during the period when the market price is highest.

In recent years, the advancement of lighting technologies in vertical farming has increasingly focused on energy-efficient, sensor-based systems that adapt to environmental conditions. Pereira and Gomes [2] developed an automated LED lighting control strategy that dynamically adjusts light intensity in response to fluctuating levels of natural daylight. Their experimental work with basil plants demonstrated that a Daily Light Integral (DLI) of 17.5 mol/($m^2 \cdot d^1$) produced the highest biomass yield while maintaining optimal energy efficiency. This approach highlights the importance of sensor-integrated lighting systems in achieving balanced productivity and sustainability in controlled environments.

Complementing this direction, Pereira [3] proposed a practical LED lighting management system in his graduate thesis, which integrates dimmers and real-time light sensors. His system was designed to respond to ambient light conditions to minimize electricity consumption while ensuring adequate illumination for plant development. The principle of tiered or layer-specific lighting employed in his study directly corresponds to the tiered LED activation strategy implemented in the A-Frame coriander growing system presented in this current research.

Further emphasizing the physiological impact of light quality, another study explored how spectral composition of LED lighting affects not only yield but also the nutritional content of vegetables grown in vertical systems. The researchers found that specific LED wavelengths enhanced the concentration of antioxidants and bioactive compounds, supporting the integration of spectrum-tuned lighting in soilless vertical cultivation [4]. These findings justify the consideration of tailored LED spectra in the coriander greenhouse system to improve both productivity and producequality.

Lastly, the study by Claydon [5] addressed the benefits of implementing complex lighting regimes in vertical farms. By dynamically adjusting light intensity and exposure time, the research demonstrated improved crop yield without a significant increase in energy consumption. Such findings reinforce the rationale for programmable lighting systems a concept closely reflected in this research's A-Frame structure, where LEDs are triggered sequentially by calibrated light sensors to ensure consistent photosynthetically active radiation (PAR) across all growing layers.

Together, these studies form a coherent body of evidence that supports the design and implementation of intelligent lighting systems in vertical farming particularly in optimizing energy use, light quality, and yield all of which are central to the current coriander cultivation model.

However, choosing high-value plants alone is not enough. The planting area must be managed to obtain a worthwhile number of plants per area. Vertical planting is a way to increase the number of plants per area.

There are many forms of vertical planting, such as the layered type, which will produce a large number of plants, but the layers will block the light. It must use only artificial light bulbs, the tube type that allows water to flow through the roots. In 1 tube, there is a complete water system inside, using natural light, and the A-Frame type is an A-shaped steel or wooden frame with hydroponic plant trays arranged in layers, offset from each other, so they do not block the sunlight from each other.

Vertical planting is popularly used with hydroponic planting. Hydroponic planting is more expensive than planting with growing media, but planting with growing media is cheaper and has fewer diseases and insects. Therefore, the idea is to use the A-Frame growing kit to grow vegetables using soil-free growing media.

Weisenhorn and Hoidal [6] determined the quality and hours of natural light in your area. Then, choose plants with light requirements that match the indoor environment. Although plants may tolerate low-light growth conditions, they may need more light to produce dense leaves and flowers.

When the light energy intensity PPFD (Photosynthetic Photon Flux Density) is 50-150 µmol m^2/s, which is low light level.

When the light energy intensity PPFD is 150-250 µmol m^2/s, which is medium light level, plants grown for flowering need it.

When the light energy intensity PPFD is 250-450 µmol m^2/s, which is high light level, artificial light is used to start seeds at this level.

LED plays a major role in vertical farm design. LED (Light Emitting Diode) lighting systems are used in vertical farms because of their energy efficiency, long lifespan, And the ability to provide an optimized light spectrum

Sarapan [7] studied the effect of wavelengths from light-emitting diodes on the growth and sugar accumulation in wheatgrass (C. sappan 60) using red, blue, green and white light-emitting diodes at a light intensity of 50 µmol m^2/s. It was found that growing young wheatgrass under red to green light at a ratio of 1:1 yielded the highest quality in terms of fresh wheatgrass weight.

In this research project, LEDs were installed on the growing layer in conjunction with sunlight, controlled by a sensor. However, the upper and lower growing layers have different light levels. Turning on the lights on all layers at the same time will waste energy, and installing sensors on all layers for control is also a waste of equipment. Therefore, the exact amount of light on each layer must be studied and the measuring device must be calibrated between the EVERFINE PLA-20 and BH1750FVI instruments to use only the top light sensor before converting it to different light intensity levels by controlling the on-off with a sensor. However, since the top and bottom growing layers have a gradient of light from high to low, turning on the lights on all layers at the same time will be wasteful, and installing sensors on all layers for control is also wasteful. This requires a study of the exact amount of light in each layer and a calibration of the measuring device between a quality measuring device and the sensor to be installed. This will allow only one sensor to be installed on the top layer and the lights to be turned on and off according to the amount of light. However, the device must be calibrated between the sensor that can display the light energy value and the sensor to be permanently installed on the layer by measuring and calibrating each layer.

This research aims to create and test soil-free vertical planting. The experiment is divided into 2 steps: the step of testing the appropriate planting material and the step of comparing the developed vertical planting layer with the conventional planting method.

2. Materials and methods

2.1 Study of suitable planting materials for the growth of coriander

Study of suitable planting materials for the growth and yield of Thai coriander in a greenhouse. The experiment was conducted in a greenhouse at the Agricultural Research and Development Office, Region 3, Sila Subdistrict, Mueang District, Khon Kaen Province, between July and September 2022. The planting materials were prepared according to the method. By planning the experiment in a randomized complete block design (RCBD) with 6 treatments, 4 replications per treatment, 3 pots per replication. The 6 treatments were as follows: 1) sand (control), 2) coconut husk : raw rice husk : black rice husk : cow dung in the ratio of 4.5:4.5:0.5:0.5, 3) coconut husk : raw rice husk : black rice husk : cow dung in the ratio of 4.0:4.0:1.0:1.0, 4) coconut husk : raw rice husk : black rice husk : cow dung in the ratio of 3.0:3.5:2.0:1.5, 5) coconut husk : raw rice husk : black rice husk : cow dung in the ratio of 2.0:3.0:3.0: 2.0 and 6) coconut husk : raw rice husk : Black rice husk : cow dung in the ratio of 1.0:2.5:4.0:2.5. Randomly collect planting materials in each process, send them for nutrient analysis at the Central Laboratory (Thailand) Co., Ltd., Khon Kaen branch, water once a day for 21 days.

Then test the water requirement of coriander, which farmers like to grow and wrap in plastic, weigh every day for 3 days, record the results, where the difference in weight of water lost each day is the amount of water the plant uses in 1 day. The average water usage rate by wrapping the pot and base of the plant in plastic is 23.21 ml/day, which means that one tray must water three plants = 69.63 ml/day.

2.2 Design an A-Frame planting set in a 6x24 m greenhouse.

Design an A-Frame planting set in a 6x24 m greenhouse, which is a closed greenhouse of the Khon Kaen Agricultural Engineering Research Center, Agricultural Engineering Research Institute, Department of Agriculture. The planting set is a 4 m long steel frame with an A-shaped cross-section, a 1.2 m wide base, 0.6 m wide on top, and 2.2 m high (Fig. 1). It can install 12 planting trays, each tray containing a long pot filled with planting materials, namely rice husks and coconut husks, which have been tested in round pots in the previous season. Design and develop a vertical planting set using intelligent artificial light and test the planting. Design and build an A-Frame vertical planting set using soil-free planting materials, 6 sets, 3 sets with automatic light bulbs, and 3 sets without light bulbs. Install a watering system and shade to reduce the temperature.

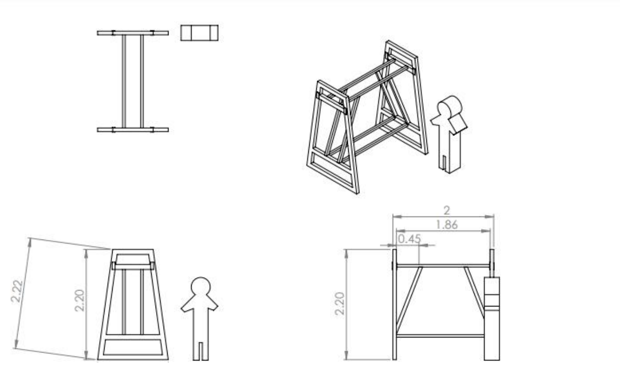

Figure 1 Desing of A-Frame for worker without climbing stairs

Study the factors affecting the growth of coriander as follows: water, temperature, humidity, fertilization, light, and the number of hours of light per day. The factors affecting plant growth were prepared to control the use in the greenhouse by using the control variables: water, temperature, humidity, fertilization, and light as independent variables.

Experimental method: Arrange the planting of coriander in 3 planting patterns:
1) 1.2 x 3 m planting table, 3 tables
2) 3 A-frame planting shelves
3) 3 A-frame planting shelves with light bulbs

Then mix the planting material, coconut husk: raw rice husk: black rice husk: cow dung in the ratio of 2.0:3.0:3.0:2.0 into the planting set of all 3 planting patterns. The planting material level in each planting pattern is 30, 20, and 10 cm, respectively. Randomly collect planting material samples and send them for nutrient analysis at the Central Laboratory (Thailand) Co., Ltd., Khon Kaen branch. Record the growth of coriander after transplanting for 42 days.

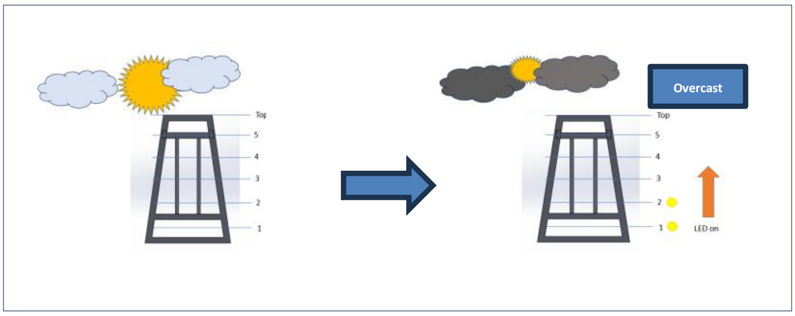

Figure 2 Diagram showing the operation of LED lighting when natural light is insufficient.

When the natural light intensity (PPFD) measured by the sensor is lower than 250 µmol m²/s at any planting layer, the LED lights at that layer will automatically turn on. The control system prioritizes lighting from the bottom layer upwards to compensate for insufficient light. This ensures that coriander plants receive a PPFD value within the optimum range of 250–450 µmol m²/s for efficient growth.

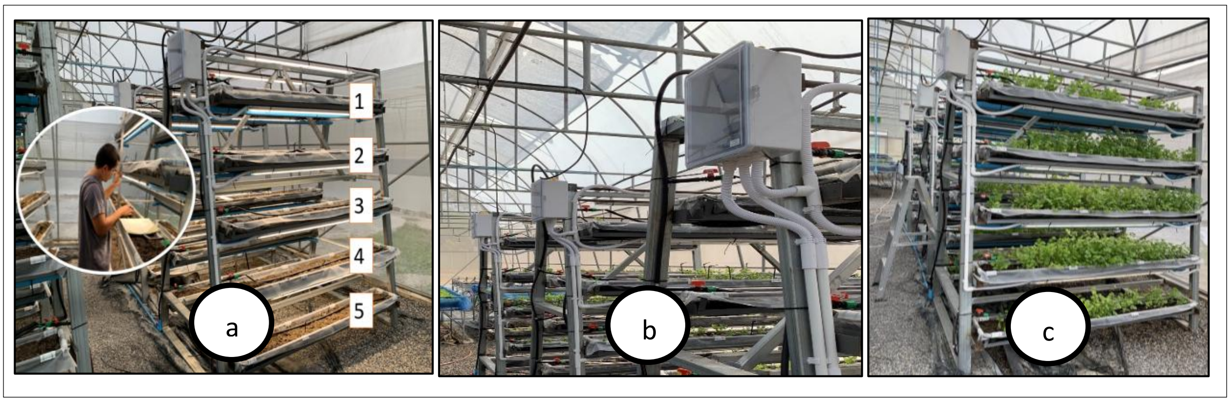

Figure 3 a) The layout of a schematic diagram of measuring b) Install the Controller on A-Frame c) Shown the A-frame device

Then mix the planting material, coconut husk: raw rice husk: black rice husk: cow dung in the ratio of 2.0:3.0:3.0:2.0 into the planting set of all 3 planting patterns. The planting material level in each planting pattern is 30, 20, and 10 cm, respectively. Randomly collect planting material samples and send them for nutrient analysis at the Central Laboratory (Thailand) Co., Ltd., Khon Kaen branch. Record the growth of coriander after transplanting for 42 days.

3. Results and discussion

Results of data collection on coriander cultivation at the Mukdahan Agricultural Research and Development Center. Coriander Rosthip variety. The planting material mixed with the formula 5 test, coconut husk: raw rice husk: black rice husk: cow dung in the ratio of 2.0:3.0:3.0:2.0. gave the highest yield, as shown in Table 1. Therefore, this planting material was selected as the experimental planting material. It was placed in all 3 types of planting sets.

Table 1 Growth and yield of coriander in each treatment

Treatment	High (cm)	Production (g)
Sand (Control)	$9.5^{c\ 1/}$	15.1^{e}
coconut coir : rice husk : burnt rice husk : Cow dung (4.5:4.5:0.5:0.5)	16.0^{b}	43.8^{d}
coconut coir : rice husk : burnt rice husk : Cow dung (4.0:4.0:1.0:1.0)	19.1^{ab}	88.5^{ab}
coconut coir : rice husk : burnt rice husk : Cow dung (3.0:3.5:2.0:1.5)	20.2^{ab}	77.6^{bc}
coconut coir : rice husk : burnt rice husk : Cow dung (2.0:3.0:3.0:2.0)	20.7^{a}	101.1^{a}
coconut coir : rice husk : burnt rice husk : Cow dung (1.0:2.5:4.0:2.5)	17.7^{ab}	59.9^{cd}
F-test	**	**
CV %	16.6	19.7

Table 2 The results of the calibration of two light metering devices.

BH1750FVI	Everfine PLA-20			
Daylight (12am)	Daylight (12am)		LED ON(7 pm)	
Lux	Lux	PPFD (μmol m^2/s)	LED ON (Lux)	PPFD (μmol m^2/s)
19700	24432	435.47	18663.1	277.6
13500	19545	343.27	18675.6	272.8
11056	15439	284.89	15457.2	242.2
10885	14875	265.12	17659.1	262.7
9876	13257	236.10	18568.8	274.3

From Table 2, it can be seen that the lux value received from BH1750FVI can be used to set the on-off range of the lights together with Everfine PLA-20 LED by setting the actual value of this sensor. However, when the lights are turned on, the planting layer will have sufficient light at high light (PPFD: 250-450 μmol m^2/s).

From the data, we can program the LEDs to turn on one layer at a time. When the sky is dark or cloudy, the LEDs on the bottom layer will turn on before the top layer and will rise to the top layer. However, when considering the data It can be seen that the lowest growing layer has a PFFD value lower than 250 μmol m^2/s. The LED light at the lowest growing layer must be on all the time.

The results of the comparison of the three types of equipment showed that the A-Frame without light bulbs gave a weight per frame of 3.1 kg, the type with light bulbs gave a weight of 2.7 kg/frame, and the type planted on a table gave a weight of 5.7 kg/table, as shown in table 3. However, even though planting on a table gave the highest yield, the purchase will focus on weight. When considering planting in a greenhouse, the A-Frame can plant 24 plants, so it can produce a higher weight per greenhouse than the type planted on a table. However, when the light bulbs were installed, it was found to be less than planting without light bulbs, which will be further improved in the light ratio.

Table 3 Growth and yield of coriander in each cropping model (mean ± SD)

Plant growing equipment	Height(cm)	Product (kg)	Productivity per Green House 6x24 m^2
A-FRAME	22.2 ± 3.6	3.1 ± 13.5	80.60
A-FRAME LED	22.5 ± 3.7	2.7 ± 15.4	70.20
TABLE	32.9 ± 3.4	5.7 ± 1.7	68.40

4. Conclusions

The results of the planting material test, the planting material ratio that gave the highest yield was coconut husk: raw rice husk: black rice husk: cow dung in the ratio of 2.0:3.0:3.0:2.0, with an average yield of up to 101 g/ plant. Therefore, this ratio was selected for the planting test.

From the experiment on the design and control of light in the greenhouse, it was found that the BH1750FVI sensor can be used to determine the time to turn on and off the LED lights together with Everfine PLA-20 effectively. By comparing the actual values of the sensor to control the appropriate lighting, the light in the planting layer with LED lights can provide high light intensity in the PPFD range of 250-450 µmol m^2/s sufficiently. In addition, programming the LED lights to turn on in a gradual manner from the bottom to the top can help increase energy efficiency, especially in conditions with low natural light, such as when the sky is dark or cloudy. Growing layers with PPFD values lower than 250 µmol m^2/s, such as the bottom layer, need to have LED lights on all the time to maintain the light intensity at the appropriate level for plant growth.

In the comparison between A-Frame without lamps, A-Frame with lamps and table top growers, it was found that growing on A-Frame without lamps gave the highest yield per greenhouse, which was 15% higher than growing on a normal table top, which makes the greenhouse more cost-effective. However, growing on a large number of A-Frames may require more light than installing additional lamps. In this regard, further development in terms of color ratio is still needed because the effect of using lamps is still less than without lamps.

5. Acknowledgements

Khon Kaen Agricultural Engineering Research Center, Agricultural Engineering Research Institute, Department of Agriculture for providing the research venue.

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