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From Concept to Cultivation: Building and Utilizing Deep Flow Technique (DFT) Hydroponics for Homegrown Urban Farming

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***Abstract*: The rapid growth of the population has increased the need for urban farming to provide food sources for residents. One innovative approach in urban farming is vertical farming, which can be implemented in urban areas with limited space. Hydroponics, a method that uses nutrient solutions instead of soil as the growing medium, is a prominent example of vertical farming. Among the various hydroponic systems, the Deep Flow Technique (DFT) is commonly utilized, characterized by a nutrient solution that flows through the installation at a specific depth. We have developed a DFT hydroponic installation constructed from lightweight steel and 3-inch PVC pipes, featuring 100 planting holes. This installation model is suitable for cultivating *Brassica rapa*, achieving a biomass productivity of 131.88 ± 12.35 grams per plant, which is higher than that obtained with the wick hydroponic system. The DFT system offers several advantages over the Nutrient Film Technique (NFT) and wick systems, including a deeper nutrient solution that reduces the need for continuous electricity and minimizes temperature fluctuations. Furthermore, the flowing nutrients in the DFT system ensure the maintenance of dissolved oxygen levels during cultivation. Moreover, several improvements can be applied to the DFT hydroponic system such as using a shallower nutrient solution depth and implementing microbubbles in the aeration system. These benefits make the DFT system well-suited for vertical farming in residential areas.**

***Keywords*: Biomass, *Brassica rapa*, DFT (Deep Flow Technique), Dissolved-Oxygen, Hydroponic, NFT (Nutrient Film Technique), Wick-system.**

1. Introduction

Modern agriculture significantly impacts soil resources as more food sources are produced to support population growth [1]. Over half of the global agriculture sector is affected by soil degradation [2]. One of the causes of soil degradation is intensive agriculture and deforestation [3]. This is based on the limited and non-renewable nature of land supply, which creates competition for land use between the agricultural and non-agricultural sectors. This condition increases agricultural land conversion, significantly reducing agricultural land availability and threatening food security [4]. Ironically, the highest rate of land conversion occurs in developing countries, which are characterized by high populations and large food consumption [5]-[6]. Additionally, unsuitable cultivation patterns also contribute to soil degradation [7]. For example, the overexploitation of agricultural land leads to land degradation, sacrificing future food production for short-term economic gain [8].

One effort to ensure food availability is the implementation of urban agriculture. Urban agriculture involves the practice of farming and livestock raising within urban areas (intra-urban) or in areas surrounding cities (peri-urban). This includes the provision of inputs and the processing of raw materials into consumable forms, followed by marketing activities [9]. The need for urban agriculture is increasing in line with the growing population and urbanization, with a predicted 9 billion people living in urban areas by 2050 [9]. This impacts the increasing conversion of urban land, which is becoming more densely populated. Innovations in urban land for urban agriculture are being implemented under the concept of "vertical farming," utilizing limited urban space [10]. By leveraging technology, urban agricultural land can be developed vertically with controlled environments, including precise lighting, nutrients, and temperature [9].

One type of vertical farm is the hydroponic method. This method uses a water medium containing nutrient solutions instead of soil. The advantage of this method is that it can be applied anywhere with access to water and light. Hydroponics with a closed system has the benefit of consuming less water and nutrients compared to an open system [11]-[12]. The hydroponic system has the potential to outperform traditional soil-based planting systems economically [13]. However, the capital and expertise required are obstacles that prevent many people from becoming hydroponic producers. Most systems require constant water circulation and continuous monitoring and adjustment of nutrients. All these inputs can incur very high costs, particularly the use of electricity [14].

The Deep Flow Technique (DFT) systems, developed in 1976, involve pumping water up from a reservoir tank and passing it through plant roots [15]. The nutrient solution remains deep enough to cover the roots, and constant circulation is usually employed to ensure sufficient oxygen

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content in the root zone [16]. The advantage of DFT over non-circulating systems is its ability to continuously provide fresh nutrient solutions, allowing for higher planting density and production per area. There is a need for a simplified form of DFT that can be used to grow various crops in limited spaces. This simplified DFT system should be capable of producing high-value crops, have reasonable water input for household scale, and maintain constant circulation with minimal energy resources [17].

In this study, we have developed a simple DFT prototype with gravity-based circulation supported by a metal frame. We tested the biomass production using green mustard (*Brassica rapa*). Furthermore, we measured the wet biomass weight produced by the DFT system. For comparison, we also cultured *Brassica rapa* in a wick system hydroponic installation as a representative of the non-circulating hydroponic system.

2. Materials and Methods

A. Hydroponic Model Build

The initial framework of the hydroponic installation was modeled using SketchUp 2018. The model specifications were created using lightweight steel materials of type-C and hollow type with dimensions of 4x4 cm. The model has a height of 2 meters and accommodates 100 planting holes. The planting holes were made using 2-meter-long PVC pipes with a diameter of 3 inches, and the planting holes were created with a diameter of 55 mm, spaced 17 cm apart. Each level of PVC pipes is connected with small pipes of 5/8 inch size. The nutrient solution from the lowest level pipe flows back into the reservoir tank. The water flow is pumped to the topmost level pipe using a pump with a capacity of 800 liter/h. Gravity will automatically cause the water to flow down to the pipes below. To increase the dissolved oxygen levels, an aerator is installed and circulated into the reservoir tank during the cultivation process. The cost of setting up this DFT hydroponic installation is approximately 1.2 million Indonesian Rupiah, or 73.58 USD.

A leak test was conducted by flowing water through the system until all pipes were filled and the water returned to the reservoir. Leaks could be detected at the pipe joints by observing for any dripping or seeping water at the connections. To address leaks at the pipe joints, waterproof tape was used to seal the connections.

The wick system installation used for comparison was prepared with a box measuring 30cm x 30cm x 20cm with 6 planting holes. The planting holes were made from wood with the same diameter as those in the DFT installation. The wick hydroponic system was used to represent a non-circulating hydroponic system.

B. Nutrition Preparation and Plant Germination

For the hydroponic nutrients, commercial AB-mix fertilizer, which contains the micronutrients and macronutrients needed by plants, was used. Each 270 grams of A and B powders were dissolved in 500 ml of distilled water to create stock solutions. The nutrients were added to the reservoir tank in a 1:1 ratio of solution A to solution B. Using a TDS meter, the nutrient concentration was checked to reach 1200 mg/L. Nutrients were added if the concentration fell below 1200 ppm, and water was added as a solvent if the nutrient concentration exceeded 1200 ppm.

Brassica rapa plants were used as the model for testing this hydroponic installation. Seed germination was conducted in rockwool medium cubes measuring 3 x 3 x 3 cm. The rockwool was then punctured at the center of the top end, and seeds were inserted into the hole. The medium was then sprayed with water until damp. The germination process for *Brassica rapa* took approximately 7 days or until the first 4 leaves appeared.

C. Plant Cultivation and Data Collection

After the seedling process, the medium was transferred into net pots measuring 7 cm in height and 4 cm in width. The net pots used were equipped with a wick made of flannel cloth. Once the net pots containing the plants were ready, they were placed into the planting holes in both the DFT and wick hydroponic installations. The cultivation process lasted for a period of 5 weeks. Nutrient levels were checked daily using a TDS meter.

Data collected in this project include the widest leaf width, leaf count, and wet biomass weight of plant samples. Data collection was conducted on the DFT hydroponic systems cultivation results.

3. Results and Discussions

A. Hydroponic Model Realization

The design of the DFT hydroponic system in this project is intended for residential use. The design is based on utilizing limited space in urban areas or home yards. The initial hydroponic installation design was created using SketchUp 2018.

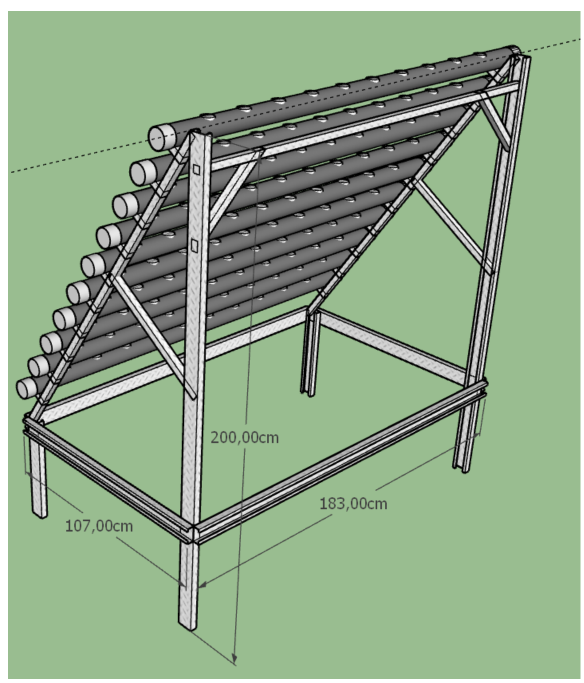

Fig. 1. Blueprint model of the DFT hydroponic installation system (rear view)

Fig. 2. Implementation of the DFT hydroponic system model with 100 planting holes (front view)

The selection of materials for the hydroponic installation is crucial. Materials need to be durable but also readily available. Lightweight steel is considered more economical due to its durability, rust resistance (coated with aluminum), light weight, strength, and quick installation time. The weight of lightweight steel material is only 6-7 kg/m², whereas wood material weighs up to 20 kg/m², making lightweight steel construction lighter than wooden frames [18].

Fig. 3. The hydroponic nutrient reservoir is connected to PVC pipes to channel the nutrient solution to the topmost section and then back to the reservoir

For the main flow system and plant placement in the hydroponic installation, 3-inch PVC pipes are used. The flow is designed to be serpentine, with the water inlet from the reservoir placed at the top and the flow meandering downwards following gravity. The flow exits through a drain hole and returns to the reservoir.

Another important consideration is the water pooling in each PVC pipe. This pooling distinguishes the DFT system from the NFT system. The flow height must be precisely 2-3 cm from the bottom of the pipe [19]. The mechanism for adjusting the water flow height in this installation is located at the pipe caps on the right and left ends of each pipe. Holes that are not centered allow the caps to be rotated to set the desired height. The end caps are not glued permanently but are sealed using removable PVAc glue.

Fig. 4. The connecting pipes between the PVC pipes allow nutrients to flow in a serpentine manner downward, following the force of gravity. The connections include (a) elbow model connecting pipes, and (b) hose connectors between the planting pipes

Fig. 5. The mechanism for adjustable caps to control the height of the nutrient water flow includes: (a) a 3-inch diameter pipe cap, and (b) 4x4 lightweight steel hollow material used as a support for the planting pipes

The water flow between pipes is facilitated using connecting pipes made of rubber, which are attached with elbow joints at the ends. This material choice is due to rubber's flexibility and resistance to breaking if bumped or shaken.

B. Cultivation Results of Brassica rapa Plants

The seeds sown in rockwool medium germinated on the third day and developed to grow four leaves by the seventh day. The medium and plants were then transferred to net pots for the cultivation process in the hydroponic installation.

Fig. 6. The process of sowing *Brassica rapa* seeds in rockwool medium and transplanting them to net pots for the cultivation process in a DFT hydroponic installation

During the cultivation process, the water volume and nutrient levels may change. To ensure the water volume and nutrient levels remain at the optimal threshold (~1200 mg/L), a digital TDS meter is used. The water volume will consistently decrease due to evaporation by the leaves, so it needs to be replenished in the reservoir. The water will deplete more rapidly as it approaches harvest time due to the larger leaf surface area, so it needs to be checked daily. If there is a nutrient deficiency due to plant intake, commercial AB-Mix fertilizer should be added to maintain the optimal nutrient level (~1200 mg/L).

Fig. 7. Nutrient content and water volume measurements were conducted periodically throughout the cultivation process to achieve optimal nutrient levels and normal water volume

The cultivation results of *Brassica rapa* using the DFT hydroponic installation showed good outcomes. The plants began to grow optimally in the 5th week. According to [20], the standard harvesting time for Brassica rapa is within 5 to 8 weeks after planting. Plant growth involves an increase in size, volume, or mass of certain organs, irreversible cell division, and cell expansion [21].

The components measured to determine the growth results of *Brassica rapa* plants grown in the DFT (Deep Flow Technique) installation system include biomass measurement, the width of the largest leaf, and the number of leaves. Here is the biomass data obtained after growing for 5 weeks.

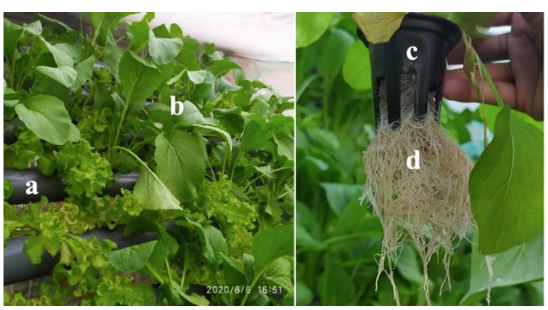

Fig. 8. Growth results after 5 weeks in the DFT system include: (a) planting hole pipes, (b) Brassica rapa subsp. parachinensis, (c) net pots, and (d) roots

For data collection, we randomly selected 6 samples from both the DFT hydroponic installation and the wick installation. A two-sample independent t-test was then conducted to test for significant differences between the cultivation outcomes with the DFT hydroponic system and the wick hydroponic system. The data is presented in Table 1. Based on the table, it was found that there is a significant difference in the mean leaf width and wet biomass weight between the two systems. However, for the mean number of leaves, there is no significant difference between the two hydroponic systems. This suggests that the difference in systems, such as open flow system (in this study, DFT) and non-circulating system like the wick system, results in differences in leaf width and wet biomass weight of *Brassica rapa* plants.

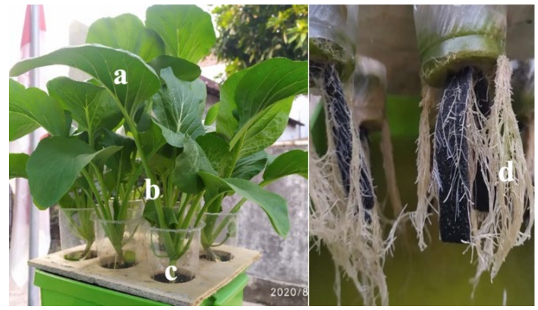

Fig. 9. Growth results after 5 weeks in the Wick system include: (a) leaf, (b) mesopodium (leaf stalk), (c) stem, (d) root

Based on the results in Table 1, the cultivation of *Brassica rapa* in the DFT hydroponic system shows higher values in the parameters of leaf width and wet biomass weight compared to the wick hydroponic system. The main reason for this is likely due to the DFT system maintaining constant water and air circulation using a water pump and air aerator. This can lead to a higher oxygen content in the nutrient solution compared to the wick system [22]. This also affects the leaf width produced in the DFT system, which is larger than in the wick system. The impact of this is that wider leaves can capture more light intensity. This is because the greater the light intensity received by the plants, the higher the plant growth due to more intensive photosynthesis processes [23].

C. The Advantages of the Deep Flow Technique Hydroponic in Homegrown Urban Area

There are three hydroponic systems commonly utilized in urban plant cultivation: the Nutrient Film Technique (NFT), Deep Flow Technique (DFT), and the wick system [24]-[27]. Both the NFT and DFT systems are favored due to their high productivity, which is attributed to the movement of nutrients and sufficient aeration essential for plant growth. In the NFT system, a thin film of nutrient solution flows through the installation pipes, partially submerging the roots. This configuration allows the roots to absorb oxygen, which supports growth [28]-[31]. The pipes are installed at an incline to facilitate nutrient flow via gravity. However, a significant drawback of this method is its reliance on electric pumps. Any malfunction or power outage can quickly result in water shortages, leading to potential production losses [32]-[37].

Table 1
Data table on average growth results of Brassica rapa in the 5th week

Hydroponic system	Leave number	The width of the largest leaf (cm)	Fresh biomass (g)
DFT System	$12.50^{a} \pm 1.04$	$14.33^{a} \pm 0.75$	$131.88^{a} \pm 12.35$
Wick System	$11.83^{a} \pm 1.47$	$12.03^{b} \pm 0.85$	$67.83^{b} \pm 11.85$

In the wick system, nutrients do not flow, classifying it as a non-circulating system. The advantage of this method is its simple design and the lack of need for electricity, as it does not require a water circulation pump. However, based on experimental data, the wick system has drawbacks, particularly concerning the level of dissolved oxygen, which is a crucial factor for plant growth. Additionally, non-circulating systems like this are susceptible to extreme temperature fluctuations, nutrient-water imbalance, and risk of nutrient buildup which can lead to suboptimal plant productivity [38]-[39].

The DFT system was created to bridge the gap between the NFT and wick systems. In this system, roots are submerged in a nutrient solution at a depth of 5-15 cm, resulting in a high amount of nutrient solution per plant [28], [40]. Additionally, the DFT hydroponic installation does not require a specific incline angle as the NFT system does [41]-[42]. This setup ensures that there is enough nutrient solution to sustain plants during periods without electrical power and nutrient circulation, and it acts as a buffer against temperature fluctuations [27]. However, since part of the roots are submerged, plants absorb fewer nutrients compared to the NFT system [28]. Nevertheless, several improvements can be made to the DFT system, such as using a shallower nutrient solution depth and implementing microbubbles in the aeration system to increase dissolved oxygen levels [42][43]-[45]. The DFT system is considered suitable for residential areas because it does not always require constant electricity and provides better growth outcomes compared to simple wick systems.

4. Conclusion

The construction of a DFT hydroponic installation using lightweight steel can be applied in urban residential areas with limited space and environments with unstable electricity conditions. Additionally, based on our activities, it has been observed that the growth of *Brassica rapa* var. parachinensis using the DFT and wick hydroponic systems shows significant differences in the variables of leaf width and biomass weight, with the DFT system yielding higher values. For the variable of the number of leaves, there is no significant difference between the DFT and wick systems. Several advantages of using the DFT system include the lack of a constant need for electricity, the periodic renewal of flowing nutrients, the maintenance of temperature stability due to the larger volume of nutrients, and the potential for improvements such as microbubble aerators and adjustable nutrient depth. These features make the DFT system well-suited for implementation in urban residential areas.

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