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Nutrition Temperature and TDS Control System with Fuzzy Logic on Pak Choy Hydroponics (Brassica rapa subsp. chinensis)

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Abstract—**Hydroponics is a method of cultivation that does not use soil as a medium, allowing it to be applied in limited spaces such as urban households. One of the vegetable plants that can be grown using hydroponics is pak choy (Brassica rapa subsp. chinensis). To produce healthy pak choy plants that can efficiently absorb nutrients in a hydroponic system, several factors need to be considered, such as the level of Total Dissolved Solids (TDS) in the nutrient solution, nutrient solution temperature, and air humidity in the hydroponic environment. The ideal nutrient solution temperature for hydroponic plants falls within the range of 25-27°C. In this system, a monitoring and control system will be designed to optimize the growth of pak choy plants in a Deep Flow Technique (DFT) hydroponic system. In this system, the nutrient solution temperature will be controlled with a set point of 25°C using an on/off control for a peltier device. To maintain the TDS level at a set point of 1200 ppm in the nutrient solution, fuzzy logic control will be employed, generating timer-based control signals for the nutrient pump A, nutrient pump B, and water pump. The monitoring system will be displayed on an Internet of Things (IoT) dashboard platform, such as ThingSpeak.**

Keywords: ***fuzzy logic, hydroponicx, monitoring, nutrition temperature, tds***

I. Introduction

Agriculture is the most critical sector in Indonesia. The availability of food is a constant necessity that the agricultural industry must meet. However, as development continues to progress in Indonesia, many agricultural lands are being converted into non-agricultural uses, such as housing complexes, industrial areas, commercial zones, and public facilities. The change has adverse effects on the economy, society, and the environment. The decline in available agricultural land results in a lower agricultural production capability, compelling the government to import agricultural goods to satisfy domestic food needs [1]. To solve this issue of land scarcity, alternative growing methods like hydroponics can be employed. Hydroponics is one of the urban farming methods that doesn't rely on soil but instead uses nutrient-rich mineral solutions or other materials containing essential nutrients like coconut coir, mineral fibers, sand, and more as substitutes for soil [2].

Various types of plants can be cultivated using hydroponic systems, including vegetables like tomatoes, cucumbers, peppers, and strawberries [3]. When caring for hydroponic plants, it's crucial to carefully monitor the timing for adding water and refreshing nutrient solutions. To efficiently water a significant quantity of hydroponic plants, an automated system capable of hydrating the plants automatically as required becomes essential [4]. Moreover, in order to boost the hydroponic market's competitiveness, farmers need to cultivate hydroponic vegetables intelligently in tropical regions to achieve both excellent quality and high crop yields [5]. One way to achieve this is by implementing a control system to support the optimization of plant growth

One of the leafy vegetable plants that can be grown in hydroponic systems is Pak choy (*Brassica rapa* subsp. *chinensis*) which is widely cultivated by Indonesian people [6]. To produce healthy Pak choy plants that can efficiently absorb nutrients in a hydroponic medium, it is important to consider factors that affect plant quality, such as TDS (Total Dissolved Solids) levels, nutrient temperature, and air humidity in the hydroponic environment. Excessively high temperatures in the nutrient solution can cause roots to wilt quickly and hinder plant growth. Several studies on the effects of temperature control on the root zone in hydroponics have been conducted by [7], [8]. Each study shows significant impacts of root-zone temperature control on the growth of hydroponic plants, where temperatures of 22°C and 25°C can provide good oxygenation in the plant nutrient solution.

Research on hydroponic monitoring has been conducted by [2], [5], [9], [10]. Each study uses different sensors, control systems, and application methods. The study by [2] aims to maintain the required ppm (Parts per Million) level for hydroponic plant growth throughout the growth process. The control system uses the ESP8266 microcontroller with ultrasonic and TDS sensors.

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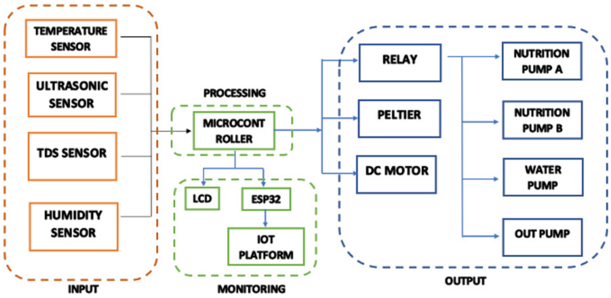

Figure 1. System block diagram

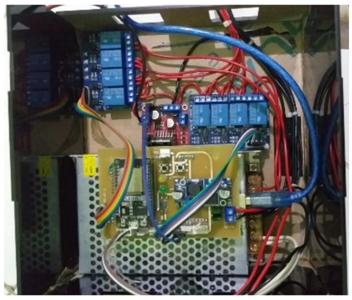

Figure 2. Hardware unit

Sensor data monitoring is conducted using the inventor application. The data communication test results show an average data transmission delay from the prototype to the Android application of 2.8 seconds [2].

Research on TDS control in hydroponic plants has been conducted by [11]-[13], each using different sensors and control systems. The study by [11] implemented TDS (Total Dissolved Solids) control in the nutrient water of the lettuce hydroponic NFT (Nutrient Film Technique) system using the PI method, which can minimize steady-state error and speed up the response to achieve a stable state. The TDS set point was set at 840 PPM, and the study resulted in an error value of 14.47% [11]. In other research, the fuzzy method was used by [14]-[16], where the control was open-loop, meaning there was no further feedback if there were changes in TDS values. The time required to reach the setpoint was 50-300 seconds, which was caused by the limited number of fuzzy rules used and the focus on changes in water volume.

From these studies, it is noted that several studies only control one parameter to optimize the nutrient water conditions, such as pH, TDS, water level, or temperature. Moreover, there is no automatic water addition system in the tank, requiring users to add water manually and measure pH and TDS parameters manually. The PI method in previous research for controlling TDS was not optimal, suggesting the need for development in methods such as Fuzzy Logic or Neural Networks. In the presentation of data in previous research, some use LCDs and IoT dashboards. However, presenting data in numerical form alone is less appealing to users, so adding graphical representations of parameter changes can be beneficial. From the evaluation of these studies, a system has been designed to control the nutrient water temperature to keep plant roots fresh and control TDS to optimize the nutrient quality for pak choy plants.

Thus, a monitoring and control system will be developed for the purpose of optimizing the growth of pak choy plants within a Deep Flow Technique (DFT) hydroponic system in this research. The DFT method is used because several studies [17]-[20] have demonstrated its advantages, such as maintaining water availability within the pipes and being able to provide water and oxygen to the plants. In this system, the nutrient solution temperature will be controlled with a set point of 25°C, and the TDS will be maintained at a set point of 1200 ppm using fuzzy logic methods. Fuzzy logic was chosen as the controller because it can be applied to most everyday systems that are nonlinear, such as in this case with the peltier temperature control [6]. In addition to maintaining the nutrient solution temperature and TDS, this system also monitors humidity and water levels through an IoT dashboard platform.

II. Method and Design

A. System Design

In this research, the authors divided the system into two parts: the TDS and nutrient water temperature control system, and the monitoring system for all conditions in the hydroponic environment, including nutrition temperature, humidity, and water level, as shown in Figure 1.

In this system, an Arduino Mega 2560 microcontroller is used, equipped with input sensors for nutrient water temperature, ultrasonic sensor for water level measurement, analog TDS sensor, and humidity sensor to detect air temperature and humidity in the vicinity of the hydroponic system, as indicated by the red box in Figure 1. The system's outputs are depicted in the blue box in Figure 1, which includes four pumps: water pump, nutrient pump A, nutrient pump B, and the peltier output pump. A motor with an L298N motor driver is used for stirring, and a peltier device is employed to maintain the water temperature at the specified setpoint.

The monitoring system, shown in the green box in Figure 1, consists of direct monitoring via the device box, which includes a 20x4 LCD displaying all the data from the sensors, and remote monitoring through an IoT platform, namely ThingSpeak, to facilitate remote monitoring of the hydroponic conditions by the user.

In Figure 2, it shows the internal box tool, which includes the wiring of Arduino Mega 2560, ESP32, TDS sensor, DHT22 sensor, ultrasonic sensor, DS18B20 sensor, along with 2 relays for powering the 12V pumps and the motor driver used for nutrient agitation.

This research has been tested in a hydroponic garden at Serpis Kebun Kita, Jemursari Street, Wonocolo District, Surabaya City, East Java, as shown in Figure 3.

Data acquisition from the module consists of several components, including the sensing device, data collection, data display on an LCD, and an IoT device.

The sensing device comprises four sensors:

- A Total Dissolved Solids (TDS) sensor by

Figure 3. Serpis kebun kita

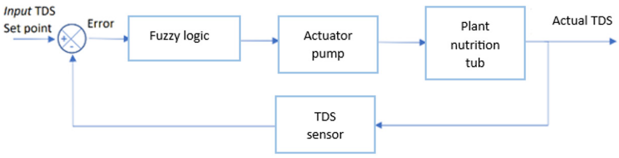

Figure 4. Fuzzy control block diagram

DFRobot, which measures the concentration of the nutrient solution in the nutrient tank, expressed in parts per million (ppm).

- A Temperature Sensor DS18B20 Waterproof by Adafruit, used for monitoring the temperature of the nutrient water in the tank.
- A Water Level Sensor that employs an ultrasonic sensor HC-SR04 to gauge the water level in the tank, as well as the levels of nutrient solution A and B in their respective containers.
- A Humidity Sensor DHT22 by Adafruit, used to measure the humidity and air temperature in the vicinity of the hydroponic garden.

The IoT device utilizes an ESP32 as an intermediary between the ATMega 2560 and the ThingSpeak platform. Data from the sensors is communicated serially for transmission to the ThingSpeak platform.

B. Method

In this research, the authors employed the Sugeno fuzzy logic method processed within the microcontroller using input values of error and delta error derived from TDS sensor readings against the specified set point, as depicted in Figure 4. All inputs are processed through fuzzification, followed by inference and defuzzification to generate decisions. The output generated from the fuzzy process is the timing for activating the water pump, nutrient pump A, and nutrient pump B until they reach the setpoint values.

The following are the membership functions used in the system, as well as the inference and fuzzification processes to determine decisions from the obtained inputs.

1. Membership Function

The membership functions used as fuzzy inputs in this system are error and delta error derived from the readings of the analog TDS sensor. Meanwhile, the output membership functions determine timers for activating the water pump, nutrient pump A, and nutrient pump B. The

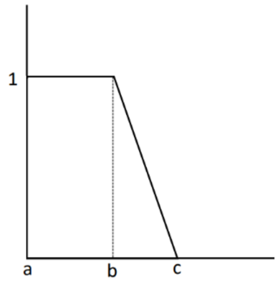

Figure 5. Linear descending curve

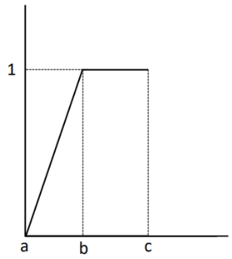

Figure 6. Linear ascending curve

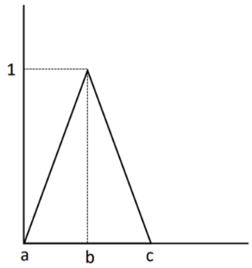

Figure 7. Tringular curve

author employs linear ascending curve, linear descending curve, and triangular curve membership functions to define each parameter. The linear descending function, as shown in the Figure 5, has three parameters, namely a, b, and c, which are expressed according to the following rules.

$$\mu(x;a,b,c)=\begin{cases}1 & ;x<b\\ \dfrac{c-x}{c-b} & ;b\le x\le c\\ 0 & ;x>c\end{cases} \tag{1}$$

The linear ascending curve is showed in Figure 6, with the lowest degree of membership on the left and rising towards higher degrees of membership to the right. The linear increasing membership function has three parameters, namely a, b, and c, as expressed by the following rules.

$$\mu(x;a,b,c)=\begin{cases}1 & ;x>b\\ \dfrac{x-a}{b-a} & ;a\le x\le b\\ 0 & ;x<a\end{cases} \tag{2}$$

The triangular curve function is illustrated in the Figure 7, with the lowest degree of membership rising to the highest degree of membership and then decreasing to the lowest degree, forming a triangular curve. This function has three parameters, namely a, b, and c, as indicated by

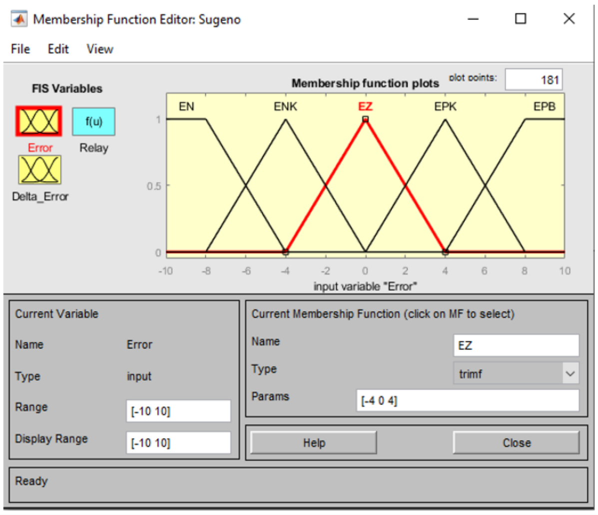

Figure 8. Membership function input error

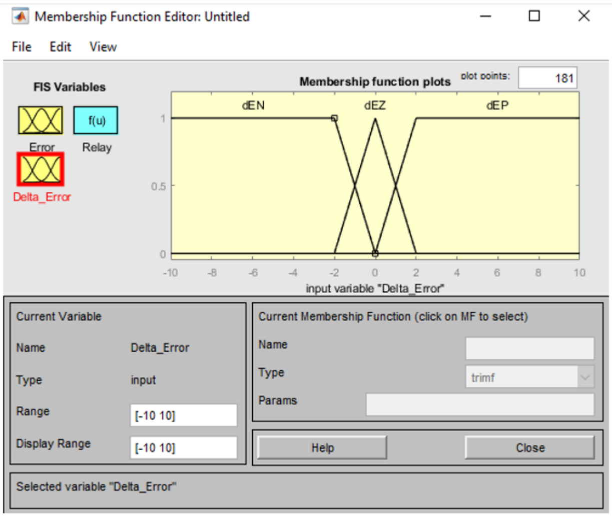

Figure 9. Membership function input delta error

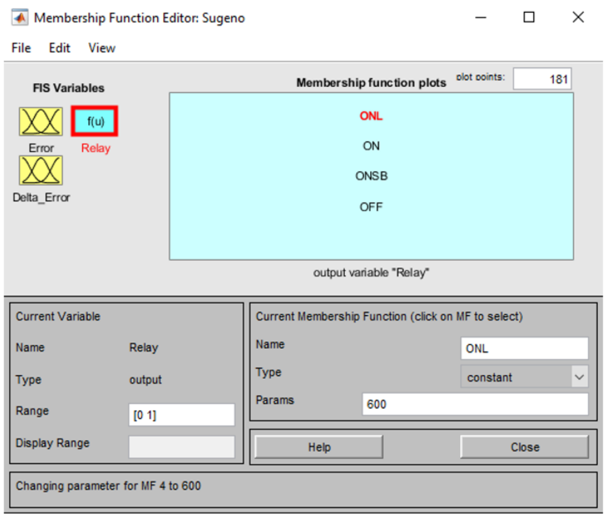

Figure 10. Membership function output

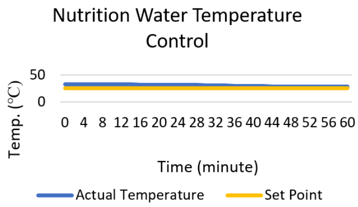

Figure 11. Graph of changes in nutrient temperature over time

the following equation.

$$\mu(x;a,b,c)=\begin{cases}0 & ;x\le a\\ \dfrac{x-a}{b-a} & ;a\le x\le b\\ \dfrac{c-x}{c-b} & ;b\le x\le c\\ 0 & ;c\le x\end{cases} \tag{3}$$

In this research, the membership functions (MF) are utilized, comprising two input MFs, namely error and delta error. The error input is calculated by the difference between the current TDS condition and the set point value. The error MF includes Negative Error (EN), Small Negative Error (ENK), Zero Error (EZ), Large Positive Error (EPB), and Large Positive Error (EP), as illustrated in Figure 8. The second input, delta error, is determined by subtracting the current error from the previous error and comprises three MFs: Delta Negative Error (dEN), Delta Zero Error (dEZ), and Large Positive Error (dEP), as depicted in Figure 9. The system's output is the activation of the pump, which is characterized by four MFs: OFF, ONSB, ON, and ONL, as shown in Figure 10.

2. Inference:

The membership degree values of the TDS error and delta TDS error in the fuzzification process will be incorporated into the rule determination process, commonly referred to as the if-then rule base fuzzy, resulting in rule strength that uses the AND operation.

3. Defuzzification:

Defuzzification is the step where each fuzzy set, resulting from the combination of fuzzy rules, is translated into a numerical value within the specific range of that fuzzy set. In this system, the centroid or Center of Area (CoA) method is employed for this purpose, reaffirming the composition of each rule to obtain the output value.

III. Result and Discussion

Based on the research in the introduction, the author presents four pieces of data: nutrition control, TDS (Total Dissolved Solids), plant comparison with and without control, and the data displayed on the ThingSpeak dashboard

A. Nutrition Water Temperature Control

In this research, a peltier device, specifically the TEC-12706 Peltier, is employed to reduce the temperature of the nutrient solution within the hydroponic tank. Figure 11 depicts a graph demonstrating the time the nutritional temperature control system takes to achieve the desired set point.

Based on the trial of nutrient temperature control using

Table 1. Data on the growth of pak choy plants without control (conventional) at Kebun Kita Serpis

Plant	Plant height (cm)		Number of leaves (pieces)	
	Week-1	Week-3	Week-1	Week-3
1	13.8	17.3	10	14
2	12.9	17.8	11	14
3	10.3	14.6	9	15
4	5.1	10.6	5	8
5	10.2	15.6	11	14
6	9.7	13	10	14
7	10.8	16.2	11	15
8	8.1	15.6	8	13
9	10.4	16.2	11	15
10	8.4	11.6	11	14
11	9.3	13.4	10	14
12	11.6	16.5	11	15
13	8.2	12.4	9	14
14	10.7	15	11	14
15	9.1	14.1	7	10
16	9	13.3	10	13
17	9.5	15	9	13
18	10.4	13	4	8
19	9.3	13.7	10	13
20	11.9	16.6	9	13

ON/OFF control of the Peltier, fan, and pump, it was found that when using one Peltier, it was able to cool the water down to 28°C in 44 minutes. The temperature drop observed was from 32.6°C to 28.05°C with a tank volume of 20x30x19 cm or 10 liters of water.

B. TDS Nutrient Control

In addition to nutrient temperature control, this system also includes fuzzy control of nutrient TDS (Total Dissolved Solids). In Figure 12 is a graph depicting the response of the TDS nutrient control system reaching the set point over time.

During the TDS nutrient recording using this fuzzy control system, data showed a gradual convergence of TDS towards the set point value over time. For this particular experiment, the set point was established at 1200 ppm, and a water tank with dimensions of 20x30x19 cm, containing 10 liters of water, was used. The operation of this system involves the TDS sensor reading the TDS level in the tank and conducting an error check against the set point every second. Subsequently, the process includes fuzzification, inference, and defuzzification. Then, every 15 seconds, an execution is carried out based on the output to activate the pump if TDS < 1200 ppm. In this test, the initial TDS in the tank was 869 ppm. It took 45 seconds for the TDS to increase from 869 ppm to 1249 ppm, in line with the set point of 1200 ppm. The controller was left running for one day in this test to ensure its proper functionality.

Table 2. Growth data of pak choy plants with control

Plant	Plant height (cm)		Number of leaves (pieces)	
	Week-1	Week-3	Week-1	Week-3
1	14	23.4	11	17
2	14.3	23	8	16
3	15.1	23.3	10	13
4	17.8	26.8	10	17
5	17.8	25.9	11	18
6	16.5	24.7	11	21
7	17.2	25.6	12	15
8	16.6	25	10	16
9	11.6	20.6	11	16
10	18.4	26.1	13	16
11	16.2	24.8	11	20
12	17	25	10	15
13	17.5	25.9	9	13
14	18.3	27.2	11	16
15	16.7	23.4	10	13
16	13	20.7	9	12
17	14.5	22.8	10	16
18	14.4	22.9	9	14
19	13	21.8	8	13
20	15.9	23.8	12	18

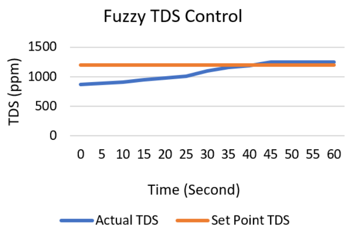

Figure 12. Graphs of changes in nutrient TDS over time

C. Comparison of plants produced

To determine the height of the plant, the measurement starts from the rockwool surface, which serves as the base of the stem, and extends to the topmost leaf of the plant. To assess the leaf count, one counts the visibly open leaves during the observation. Data from plants without control were obtained from plants grown conventionally by hydroponic farmers in the Serpis garden of Jemursari, Surabaya. The comparison plants consisted of 20 plants that were 7 days old from the time of planting in the hydroponic growing medium, as shown in Figure 13. Table 1 is the data from the plants in the conventional hydroponic garden.

Meanwhile, control planting was carried out on the same day. Table 2 shows data on the height and number of leaves of pak choy plants using the system that has been created.

From the data in Tables 1 and 2, the plants conventionally grown by hydroponic farmers in the Serpis garden have an average growth rate of 0.232 cm per day,

Figure 13. Pak choy plants without control at Kebun Kita Serpis

Figure 14. Pak choy plants with control

Figure 15. Display sensor data on the ThingSpeak dashboard

and on average, they gain 3-4 leaves every 20 days.

On the other hand, pak choy plants with control experience an increase of 3-8 leaves every 20 days and have an average growth rate of 0.42 cm per day, which means that the controlled plants have a growth rate that is 1.8 times faster than the pak choy plants grown without control. This is due to several factors, such as the TDS (Total Dissolved Solids) values in the hydroponic garden not being continuously monitored, causing TDS to drop below the required range for pak choy. Controlled plants have greener and fresher leaves compared to plants without control. Additionally, the weight of pak choy plants with control is 1.42 times heavier than the weight of pak choy plants without control, as shown in Figure 14.

D. Dashboard Display

All sensor readings, including data on air temperature, humidity, water temperature, TDS (Total Dissolved Solids), and water level, are displayed on the ThingSpeak dashboard. Figure 15 below shows the data display on the ThingSpeak dashboard.

Data from the sensors processed by Arduino Mega 2560 is sent to the ESP32 through serial communication and then transmitted to the ThingSpeak dashboard every 15 seconds.

IV. Conclusion

After performing the installation of the system design and development, it was followed by the installation of testing and the evaluation of the overall control system test results automatically using fuzzy logic methods. It can be concluded that this system can control the nutrient temperature at 28.05°C within 44 minutes. The fuzzy controller can reach the set point of 1200 ppm in 45 seconds. Plants grown under control exhibit a faster growth rate of 0.42 cm/day, while plants without control yield a growth rate of 0.232 cm/day, meaning that controlled plants grow 1.8 times faster than pak choy plants grown without control. Therefore, this control system can improve the quality and accelerate the harvest time of pak choy. All data read by the sensors are successfully transmitted to the ThingSpeak dashboard every 15 seconds.

Reference

[1] H. and N. Suranta, “Intelligent monitoring and controlling system for hydroponics precision,” in Proc. International Conference on Information and Communication Technology, 2019, pp.1-6.

[2] A. D. Purwanto, F. Supegina, and M. T. Kadarina, “Sistem kontrol dan monitor suplai nutrisi hidroponik sistem deep flow technique (DFT) berbasis arduino nodeMCU dan aplikasi android,” *Jurnal Teknologi Elektro*, vol. 10, pp. 152-158, 2019.

[3] N. Sharma, S. Acharya, K. Kumar, N. Singh, and O. Chaurasia, “Hydroponics as an advanced technique for vegetable production: An overview,” *Journal of Soil and Water Conservation*, vol. XVII, no. 4, pp. 366-371, 2018.

[4] P. Sihombing, N. A. Karina, J. T. Tarigan, and M. I. Syarif, “Automated hydroponics nutrition plants systems using arduino uno microcontroller based on android,” *Journal of Physics*, vol. 978, pp. 1-6, 2018.

[5] J. Chaiwongsai, “Automatic control and management system for automatic control and management system for tropical hydroponic cultivation,” in Proc. International Symposium on Circuits and Systems, 2019, pp. 1-4.

[6] A. Raksun, M. L. Ilhamdi, I. M. Merta, and I. G. Mertha, “Vegetative growth of Pakcoy (Brassica rapa L.) due to different dose of bokashi and NPK fertilizer,” *Jurnal Biologi Tropis*, vol. XX, no. 3, pp. 452-459, 2020.

[7] M. S. Al-Rawahy, S. A. Al-Rawahy, Y. A. Al-Mulla, and S. K. Nadaf, “Effect of cooling root-zone temperature on growth, yield and nutrient uptake in cucumber grown in hydroponic system during summer season in cooled greenhouse,” *Journal of Agricultural Science*, vol. XI, no. 1, pp. 47-60, 2019.

[8] M. S. Al-Rawahy, S. A. Al-Rawahy, Y. A. Al-Mulla, and S. K. Nadaf, "Influence of nutrient solution temperature on its oxygen level and growth, yield and quality of hydroponic cucumber," *Journal of Agricultural Science*, vol. XI, no. 3, pp. 75-92, 2019.

[9] S. Pramono, A. Nuruddin, and M. H. Ibrahim, "Design of a hydroponic monitoring system with deep flow technique (DFT)," in Proc. International Conference on Industrial, Mechanical, Electrical, and Chemical Engineering, 2020, pp.1-8.

[10] C. J. G. Aliac and E. Maravillas, "IOT hydroponics management system," in Proc. International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management, 2018, pp.1-5.

[11] N. Insyani, M. R. Kirom, and A. Qurthobi, "Pengaruh kontrol nutrisi dengan menggunakan proportional integral ziegler nichols terhadap produksi selada," e-Proceeding of Engineering, vol. VII, no. 1, pp. 1221-1229, 2020.

[12] S. N. Sholihat, M. R. Kirom, and D. I. W. Fathonah, "The Effect of nutrient control on the growth of kangkung with hydroponic nutrient film technique (NFT) method," Proceeding of Engineering, vol. V, no. 1, pp. 910-915, 2018.

[13] M. L. Andhikaputra, A. Faisol, and K. Auliasari, "Penerapan metode fuzzy pada sistem monitoring perkembangan tanaman hidroponik," *Jurnal Mahasiswa Teknik Informatika*, vol. V, no. 1, pp. 299-307, 2021.

[14] F. Suryatini, S. Pancono, S. B. Bhaskoro, and P. M. S. Muljono, "Sistem kendali nutrisi hidroponik berbasis fuzzy logic berdasarkan objek tanam," *Jurnal Teknik Energi Elektrik, Teknik Telekomunikasi, & Teknik Elektronika,* vol. IX, no. 2, pp. 263-278, 2021.

[15] M. M. Fatori, "Aplikasi IoT pada sistem kontrol dan monitoring tanaman hidroponik," *Jurnal Pendidikan Sains dan Komputer,* vol. II, no. 2, pp. 350-356, 2022.

[16] A. N. Sholihah, A. R. A. Tahtawi, and S. W. Jadmiko, "TDS control system for hydroponic deep flow technique nutrition using fuzzy logic," *Journal of Electrical Engineering and Information Technology,* vol. XIX, no. 1, pp. 1-5, 2021.

[17] F. I. N. Sofiyanti and R. M. Roza, "Penerapan teknologi hidroponik sistem deep flow technique sebagai usaha peningkatan pendapatan petani di desa Sungai Bawang," *Riau Journal of Empowerment,* vol. I, no. 1, pp. 23-29, 2018.

[18] J. E. Son, H. J. Kim and T. I. Ahn, "Hydroponic systems," in Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production, Seoul, Academic Press, 2020, pp. 273-283

[19] B. Wingsamut and M. E. L. Wingsamut, "Assessment of four species of vegetables grown in deep flow technique and nutrient film technique hydroponic systems," *International Journal of Agricultural Technology*, vol. 17, no. 3, pp. 1183-1198, 2021.

[20] N. Hafizah, F. Adriani, and M. Luthfi, "Pengaruh berbagai komposisi media tanam hidroponik sistem DFT pada pertumbuhan dan hasil tanaman Selada (Lactuca sativa L.)," *Jurnal Sains STIPER Amuntai*, vol. 9, no. 2, pp. 62-67, 2019.