

## Potential Analysis of the Application of Fuzzy Logic in the Optimization of Pak Choi Hydroponic Cultivation: A Literature Study on Plant Growth Support System

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### Abstract

The rapid urbanization and increasing population density in Indonesia have led to a reduction in available land for traditional agriculture, particularly in urban centers. In response to this challenge, urban farming, including hydroponic cultivation, has emerged as a viable solution to meet the food needs of urban communities. This study explores the potential application of fuzzy logic in optimizing hydroponic cultivation practices, focusing on the growth of pak choi plants. Pak choi, a popular vegetable in Indonesia, offers numerous health benefits and is well-suited for hydroponic cultivation. By analyzing relevant literature, this research investigates the influence of water pH and temperature on pak choi plant growth and develops a fuzzy expert system based on Mamdani's method. The study prepares data on optimal temperature and pH ranges for pak choi cultivation and establishes fuzzy sets for water temperature, water pH level, and plant height. Fuzzy rules are formulated to create a rule base for the fuzzy expert system. The findings provide insights into the effects of water pH and temperature on pak choi plant growth and demonstrate the potential of fuzzy logic in optimizing hydroponic cultivation practices. This research contributes to the advancement of agricultural technology and offers practical solutions for sustainable urban farming.

**Keywords:** Fuzzy logic, Hydroponic cultivation, Pak choi plants, Water pH level, Water temperature.

### INTRODUCTION

Based on the Central Statistics Agency (BPS) 2023, Indonesia currently has a population of around 277.7 million people, making it one of the 4th most populous countries in the world. The population density that occurs makes the land that can be used for agriculture decreases, especially in big cities that become industrial centers. This condition is the reason for the phenomenon of urban farming which encourages people to fulfill their food needs independently as well as agricultural solutions in urban areas. One method of implementing urban farming is hydroponic farming.

Hydroponics is a method of growing plants without the use of a soil-based growing medium. Hydroponics literally means planting in water that contains a mixture of nutrients. In today's practice, hydroponics is inseparable from the use of other non-soil growing media to support plant growth. The hydroponic system is a very effective way of plant production. This system was developed based on the reasoning that if plants are given optimal growing conditions, then the maximum potential for production can be achieved. This is related to the growth of the plant root system, where optimum plant root growth will result in very high shoot or top growth. In hydroponic systems, the nutrient solution provided contains a balanced composition of organic salts to grow roots with ideal root environmental conditions (Dani, 2020).

In hydroponic vegetable cultivation, it is necessary to consider factors that affect plant growth. These factors include the acidity or alkalinity of the growing medium water, the supply of nutrients absorbed through the plant roots, and the air temperature of the growing medium environment. In practice, after being adjusted to the needs of vegetables, the value of these factors can change continuously, so a system is needed that can regulate the values of vegetable needs factors. With this need, the author analyzes the application of fuzzy systems for optimizing hydroponic plant cultivation with a case study of pak choi plants.

Pak choi is a popular vegetable crop among Indonesian farmers because it is easy to grow, either by planting directly in the ground or using modern methods such as hydroponic systems. According to the Aggregate Nutrient Density Index, Pak choi is placed third in the category of nutrient-dense fruits and vegetables, after Cabbage and Collard Greens. Pak choi also contains various nutrients that are beneficial to human health, including protein, carbohydrates, fiber, potassium, vitamins A, C, B6, calcium, magnesium, and iron. Pak choi has a myriad of health benefits, including cancer prevention, lowering high blood pressure, reducing the risk of heart disease, maintaining eye health, strengthening bones, increasing endurance, and removing wrinkles on the skin (Furhman, 2017).

Logic control in fuzzy systems can be a solution to the study of problems in this research. From various applications of fuzzy logic that have been carried out, it shows that if a system has uncertain properties or values, it can be controlled using fuzzy logic control. In fuzzy logic, there is a degree of membership that has a value range of 0 to 1. Fuzzy logic is used to translate a quantity expressed using language (linguistic), for example the amount of vehicle speed expressed by slow, rather fast, fast and very fast. Fuzzy logic indicates the extent to which a value is true and the extent to which a value is false. Unlike classical logic, a value only has 2 possibilities, namely a member of the set or not. The degree of membership 0 (zero) means that the value is not a member of the set and 1 (one) means that the value is a member of the set (Kurniati, Triyanto & Rismawan, 2017).

In this study, the process of analyzing the effect of pH and water temperature on the growth of pak choi plant height using fuzzy logic with a fuzzy expert system will be discussed. There are three temperature variables that are input, namely cold temperature, medium temperature, and hot temperature. Likewise for pH variables, low pH, medium pH, and high pH. For output there will be three variables, namely short, medium, and tall pak choi plants.

Fuzzy expert system is an expert system whose rule base formation process uses a fuzzy system. The sequence in the formation of a fuzzy expert system is the process of fuzzification, fuzzy inference system and de-fuzzification. The first step taken in the formation of a fuzzy expert system is to form input and output variables of the fuzzy set. So that the fuzzification process can be carried out. Fuzzification is the process of translating crisp inputs into fuzzy sets. Meanwhile, the fuzzy inference system is a model of drawing conclusions from a set of fuzzy rules that have been made. In this study using the Mamdani model. De-fuzzification is the process of forming the output value in the form of a fuzzy set into a set of crisp numbers (Yunus 2017).

## **METHODS**

This research was conducted at IPB University Vocational School, located at Jl. Kumbang No.14, RT.02/RW.06, Babakan, Central Bogor District, Bogor City, West Java, with a span of three weeks starting from February 18 to March 8, 2024. The research covers from the beginning of data search, data processing, to the analysis of data processing results using fuzzy logic.

The research methodology is based on a thorough analysis of relevant literature studies that have been published in scientific journals, conferences, and trusted academic text sources. This approach involved the search, selection, and synthesis of relevant information related to the application of fuzzy logic in the optimization of pak choi hydroponic cultivation and the development of plant growth support systems. The information obtained from this literature was then critically analyzed to identify, methodological approaches, and key findings related to this research topic. In developing the fuzzy logic to be analyzed, the following steps were applied:

### **1. Data Preparation**

This step is useful for preparing data that will be processed for research purposes. In this case, the data is in the form of water temperature and pH in the planting medium for pak choi plants and plant height which is used as a reference for research through literature studies.

## 2. Variable Linguistic

Formation of fuzzy variables and sets equipped with fuzzy domain values and fuzzy parameters used.

## 3. Inference Method

An analysis is carried out to determine the right inference method for building a fuzzy expert system. The inference method chosen is the Mamdani fuzzy inference system (FIS).

## 4. Defuzzification Method

An analysis is needed to determine the right defuzzification method to produce the right output as well, the defuzzification method used is the centroid method.

One of the literatures that the author makes as a reference in this research is "Optimizing Growth in Nutrient Film Technique Hydroponic Vegetables with the Internet of Things-Based Fuzzy Logic Method" written by Ahmad Wahyu Dani. Dani (2020) in his research, has the main parts of the control system in the tool made, namely input, process, and output. The input consists of 3 sensors, namely the nutrient sensor, acidity sensor, and temperature sensor. The TDS meter value is converted into two inputs, namely the error and delta error values used in the calculation of fuzzy logic of nutrient levels. The same calculation is also carried out in the fuzzy logic calculation of acidity levels and fuzzy logic calculation of cooling temperature. The process part is handled by the arduino mega 2560 microcontroller which runs the fuzzy calculation program and other system support programs. The output consists of 4 parts, namely output for nutrient pumps A and B, used to send data from the arduino mega 2560 via serial communication to the firebase realtime database. The difference between this research and the research conducted by the author is that this research uses 3 inputs, namely the nutrient sensor (TDS), temperature sensor (DS18B20), and acidity sensor (pH meter), while the research conducted by the author only uses 2 inputs, namely the nutrient sensor (TDS) and temperature sensor (DS18B20) because it only requires 2 sensor inputs.

Farhan et al. (2023), wrote a journal entitled Hydroponic Media Turbidity and pH Control System for Watercress using Fuzzy Algorithm. The research aims to implement Real-Time Fuzzy Logic Control for vertical hydroponic systems based on Arduino Uno. The research was conducted in several stages, namely literature study, needs analysis, design and implementation, testing, and conclusion. At the testing stage, the resulting watercress plants are expected to be better and healthier than watercress in supermarkets or available sales places. The difference between the journal and the journal that the author is doing is that the journal examines watercress as the object of research, while the author is examining pak choi vegetables that will be optimized for growth.

## RESULTS AND DISCUSSION

Based on the system development method previously described, this discussion section will describe the results of the potential analysis of the application of fuzzy logic in optimizing hydroponic cultivation of pak choi plants using the fuzzy logic mamdani method. The input of the applied fuzzy logic is the pH value and water temperature in the pak choi hydroponic planting method as data for calculation so that it produces how much pH and temperature is sufficient to produce optimal pak choi height growth.

### 1. Data Preparation

After conducting a thorough analysis of relevant literature studies, it was found that the optimal temperature range for hydroponic pak choi cultivation is between 18-24°C (Saptorini, 2021). This range is crucial for the growth and development of the plant, ensuring its health and productivity. Maintaining this temperature range can be achieved through the use of a microcontroller-based system to control temperature and humidity (Usman, 2019).

For pH parameter input (M Sunail Huda et al, 2023) The best growth and yield of pak choi plants were obtained from the P2 treatment (pH: 6.5), while the worst growth and yield of pak choi plants were obtained from the P3 treatment (pH: 8). In his research, he conducted experiments with 3 treatments on plants, namely pH = 5, pH = 6.5 and pH = 8, each of which was repeated nine times. The results showed that the different pH treatments showed significantly different effects on the growth and yield of pak choi plants ... (M Sunail Huda et al, 2023). For output, the average height of pak choi plants grown hydroponically varied depending on the conditions and techniques

used. However, research shows that hydroponically grown pak choi can reach a height of 20-30 cm (Iskandar, 2021).

## 2. Variable Linguistic

Linguistic variables are descriptions of system inputs and outputs in the form of natural language or linguistics so that they are easily understood by humans. This stage is carried out by forming fuzzy variables and sets equipped with fuzzy domain values and fuzzy parameters used. These linguistic variables determine the input and output domains of the system.

Table 1. Type, Variable, and Range Used

Type	Variable	Range
Input	Water Temperature	[12 30]
	Water pH level	[5 8]
Output	Plant Height	[0 30]

**Table 1** provides information on the types, variables, and ranges used in this study. In the water temperature variable, it is found that the optimal temperature for pak choi growth is in the range of 18-24 ° C, but the range of temperature variables used in this study is 12-30 ° C. With the calculation of the optimal temperature range from 18-24 ° C is 6 ° C, so for the cold temperature variable, the temperature is expanded to 6 ° C below 18 and 6 ° C above 24 so that a range of 12-30 ° C is produced.

The water pH variable uses a range according to the references found in the literature study conducted. In the plant height variable, the range 0-30cm is used with an expansion of 10cm from the known data that the height of pak choi grown hydroponically can grow in the range of 20-30cm. This expansion is done for the plant height variable data in the short set.

The following is the formation of fuzzy set variables used in this study:

Table 2. Water Temperature (°C) Input

Water Temperature (°C)	
Condition	Set
Cold	[12, 12, 15, 18]
Medium	[18, 21, 24]
Hot	[24, 27, 30, 30]

**Table 2** describes the set of water temperature variables with cold, medium, and hot conditions. In cold and hot conditions there are 4 variables because they use a trapezoidal membership function on the grounds that the two variables have a wider range and are not symmetrical because their values are not known with certainty. Meanwhile, the medium variable uses a triangular membership function because its value is clearly known. With this set, the following input graph is obtained:

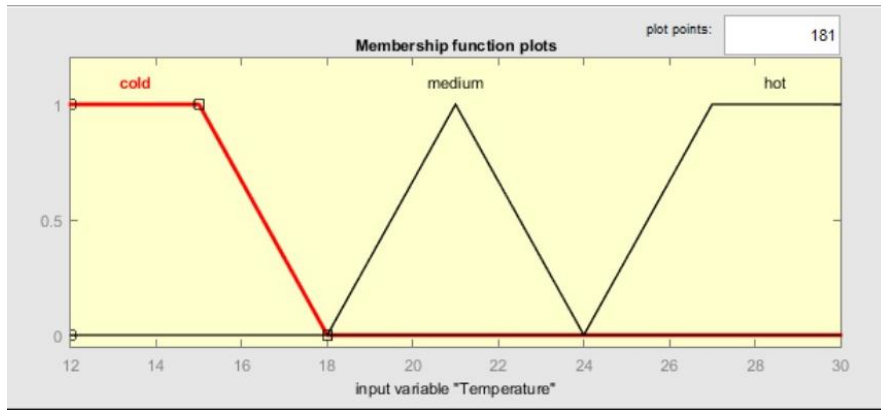


Figure 1. Graphic Water Temperature (°C) Input

**Figure 1** shows the input graph of water temperature that has 3 conditions, namely cold, medium, and hot that created from the value received and then adjusted to the existing range. The following data in the table is set variable of each conditions for water pH level:

Table 3. Water pH level Input

Water pH level	
Condition	Set
Low	[5, 5, 5.5, 6]
Medium	[5.5, 6.25, 6.5]
High	[6, 6.5, 7, 8]

**Table 3** provides information about the set of variable water pH levels with low, medium, and high conditions. In low and high conditions a trapezoidal membership function is used and in medium conditions a triangular membership function is used. With this set, the following input graph is obtained:

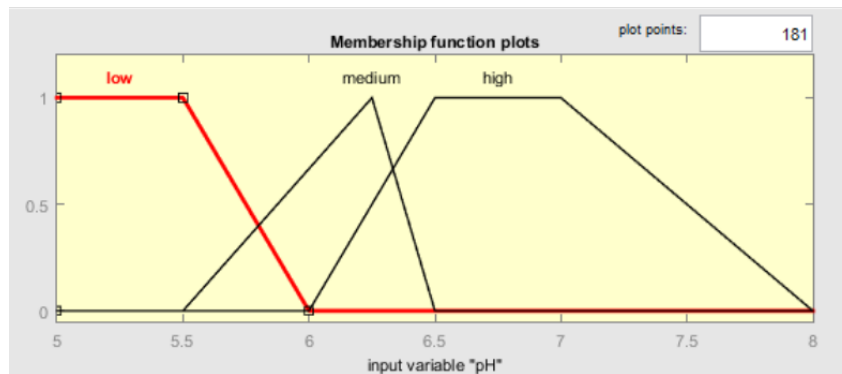


Figure 2. Graphic Water pH level Input

Then for the output value, the linguistic variable is the height of the pak choi plant as presented in the table below:

Table 4. Plant Height (Output)

Plant Height (cm)	
Condition	Set
Short	[0, 5, 10]
Medium	[10, 15, 20]
Tall	[20, 25, 30]

**Table 4** provides information about the set of plant height variables with short, medium, and tall conditions. All conditions use a triangular membership function which is characterized by only three members in the set. With this set, the following input graph is obtained:

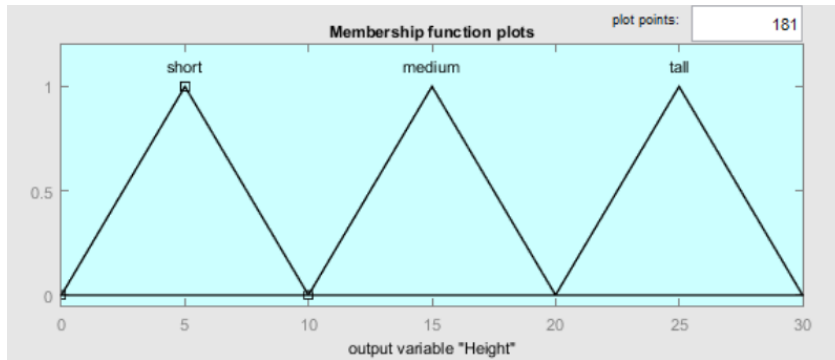


Figure 3. Graphics Plant Height (Output)

Figure 3 shows the output graph of a fuzzy rule that has 3 conditions, namely short, medium, and tall that created from the input received and then adjusted to the existing range.

### 3. Inference Method

The inference method is carried out by analysis which aims to determine the right inference method to build a fuzzy expert system. Previously, fuzzy rules were determined using MATLAB tool box based on the data in Table 1, Table 2, Table 3, and Table 4. In the figure below there are nine fuzzy rules that use the AND operator for each IF-THEN condition.

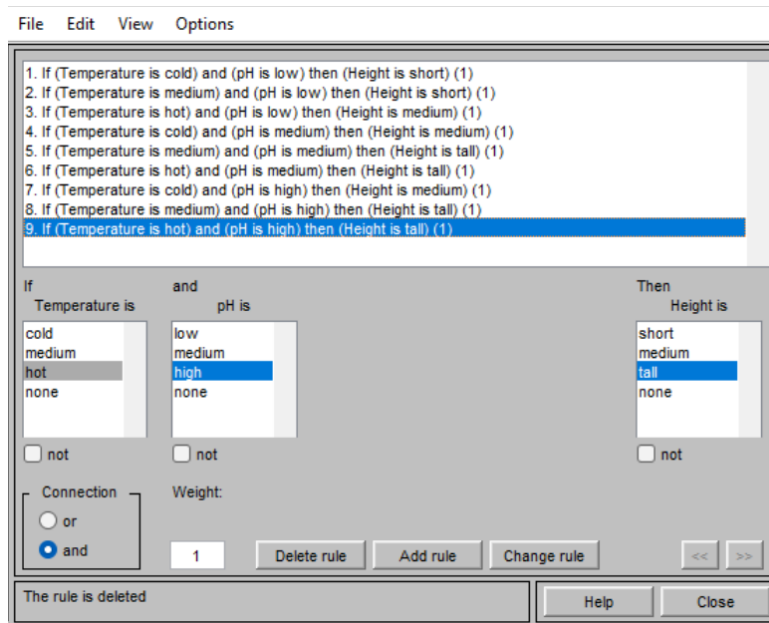


Figure 4. Fuzzy Rules on Matlab

The fuzzy rules that have been created in matlab will be described in the table below:

Table 5. Fuzzy Rules

No	Temperature	pH Level	Plant Height
1	Cold	Low	Short
2	Medium	Low	Short
3	Hot	Low	Medium
4	Cold	Medium	Medium
5	Medium	Medium	Tall
6	Hot	Medium	Tall
7	Cold	High	Medium
8	Medium	High	Tall

After the fuzzy rules are known, then proceed to the inference method. The inference method in this research starts by defining membership sets for input variables whose values can determine the output to be issued. After the membership sets are defined, the next step is to calculate the membership degree of each fuzzy set based on the input values generated from the activated fuzzy rules. The following is the explanation:

a. Membership Set

The membership set is made based on the literature study and analysis carried out which is adjusted to the graph made in the MATLAB application. This set can be used to calculate the height growth of pak choi based on each parameter to determine the degree of membership ( $\mu_x$ ).

The following data is the membership set function of the input:

$$Fx(\text{Water Temperature}(^{\circ}\text{C})) \left\{ \begin{array}{l} \mu_{Cold} = \begin{cases} 0 & ; x \leq 12 \\ \frac{x-12}{12-12} & ; 12 \leq x \leq 12 \\ 1 & ; 12 \leq x \leq 15 \\ \frac{18-x}{18-15} & ; 15 \leq x \leq 18 \\ 0 & ; x \geq 18 \end{cases} \\ \mu_{Medium} = \begin{cases} 0 & ; x \leq 18 \\ \frac{x-18}{21-18} & ; 18 \leq x \leq 21 \\ \frac{24-x}{24-175} & ; 21 \leq x \leq 24 \\ 0 & ; x \geq 24 \end{cases} \\ \mu_{Hot} = \begin{cases} 0 & ; x \leq 24 \\ \frac{x-24}{27-24} & ; 24 \leq x \leq 27 \\ 1 & ; 27 \leq x \leq 30 \\ \frac{30-x}{30-30} & ; 30 \leq x \leq 30 \\ 0 & ; x \geq 30 \end{cases} \end{array} \right.$$

$$Fx(\text{Water pH Level}) \left\{ \begin{array}{l} \mu_{Low} = \begin{cases} 0 & ; x \leq 5 \\ \frac{x-5}{5-5} & ; 5 \leq x \leq 5 \\ 1 & ; 5 \leq x \leq 5.5 \\ \frac{6-x}{6-5.5} & ; 5.5 \leq x \leq 6 \\ 0 & ; x \geq 6 \end{cases} \\ \mu_{Medium} = \begin{cases} 0 & ; x \leq 5.5 \\ \frac{x-5.5}{6.25-5.5} & ; 5.5 \leq x \leq 6.25 \\ \frac{6.5-x}{6.5-6.25} & ; 6.25 \leq x \leq 6.5 \\ 0 & ; x \geq 6.5 \end{cases} \\ \mu_{High} = \begin{cases} 0 & ; x \leq 6 \\ \frac{x-6}{6.5-6} & ; 6 \leq x \leq 6.5 \\ 1 & ; 6.5 \leq x \leq 7 \\ \frac{8-x}{8-7} & ; 7 \leq x \leq 8 \\ 0 & ; x \geq 8 \end{cases} \end{array} \right.$$

Using the membership set that has been established based on the literature study and analysis, the height growth of pak choi can be calculated based on each parameter to determine the membership degree ( $\mu_x$ ). Thus, this membership function provides a useful framework in relating input values to plant growth rates. With this membership set, a more appropriate decision can be formulated based on the given environmental conditions.

b. Membership degree

The next step is to calculate the membership degree of each fuzzy set based on the input values given by the activated fuzzy rules. These membership degree values are calculated using the "min" operator to select the smallest value of the membership degree corresponding to the activated fuzzy rule.

Based on the membership set data above, for example, calculations can be made to determine the height of pak choi plants if the water temperature is 25°C or hot and the water pH level is at a value of 6.5 or high. Then the membership degree ( $\mu_x$ ) of the water pH level will be 1 and the membership degree ( $\mu_x$ ) of the water temperature will be calculated with the following explanation:

$$\mu_x \text{ Water Temperature} = \frac{x - 24}{27 - 24} = \frac{25 - 24}{27 - 24} = \frac{1}{3} = 0.33$$

$$\mu_x \text{ Water pH Level} = 6.5 \leq x \leq 7$$

$$\mu_x \text{ Water pH Level} = x = 6.5 = 1$$

From the example above, if we have data that the water temperature is 25°C or hot and the pH level of the water is at a value of 6.5 or high, it will enter into the 9th rule which is "if the temperature is hot and the pH level is high, the plants will be high", from this rule we get the following formula:

$$\alpha = \min(0.33 \cap 1)$$

$$\alpha = \min(0.33 ; 1)$$

$$\alpha = 0.33$$

This case uses the AND operator so that the membership degree value taken is the smallest value that will be used to calculate the X1 and X2 values in the output variable. The next step of the fuzzy mamdani method is to calculate the values of X1 and X2 on the output graph, determine the membership set of the output variable, the area, and the moment equation performed in the defuzzification process.

#### 4. Defuzzyfikasi

The defuzzification process is carried out to ensure that the output generated from the fuzzy expert system is an understandable form and can be used in making decisions or further actions. By checking the output generated through defuzzification with manual calculations, the accuracy and reliability of the results obtained from the fuzzy expert system can be verified. There are several calculation processes carried out to produce defuzzification using the centroid method. Centroid method is one of the commonly used methods in defuzzification to calculate the output value of the activated fuzzy set.

The defuzzification process begins by determining the X1 and X2 values from the previously calculated sample data. These X1 and X2 values are taken and determined from the output variable graph and based on the rules used. In calculating the X1 and X2 values, the range taken is the tall set. Therefore from the tall output graph, it can be seen that a = 20 b = 25 c = 30, the following explanation:

$$\alpha = \frac{x1 - a}{b - a}$$

$$0.33 = \frac{x1 - 20}{25 - 20}$$

$$\alpha = \frac{c - x2}{c - b}$$

$$0.33 = \frac{30 - x2}{30 - 25}$$

$$0.33 = \frac{x_1 - 20}{5} \rightarrow 0.33 \cdot 5 = x_1 - 20$$

$$0.33 = \frac{30 - x_2}{5} \rightarrow 0.33 \times 5 = 30 - x_2$$

$$1.65 = x_1 - 20 \rightarrow 1.65 + 20 = x_1$$

$$1.65 = 30 - x_2 \rightarrow x_2 = 30 - 1.65$$

$$X_1 = 21.65$$

$$X_2 = 28.35$$

∴ The value of **X1 is 21.65** and **X2 is 28.35**

After the X1 and X2 values are generated, the area can then be calculated and formed. membership set on the output variable as follows:

#### Area

$$\text{LD I (Triiangle)} = \frac{a \cdot t}{2} = \frac{(21.65 - 20) \times 0.33}{2} = \frac{0.544}{2} = 0.272$$

$$\text{LD II (Rectangle)} = p \cdot l = (28.35 - 21.65) \times 0.33 = 6.7 \times 0.33 = 2.211$$

$$\text{LD III (Triiangle)} = \frac{a \cdot t}{2} = \frac{(30 - 28.35) \times 0.33}{2} = \frac{0.544}{2} = 0.272$$

∴ The value of **LD I is 0.272**, **LD II is 2.211**, and **LD III is 0.272**

Calculating the area after the X1 and X2 values are generated is useful for determining the area under the membership function curve of the output variable. Each linguistic set in the output variable is usually represented as a curve or a subset of a graph. Calculating the area under the curve of each linguistic set can help to determine how much each linguistic set contributes to the output value to be generated.

#### Moment Calculation

In defuzzification, moments are used to calculate the concrete output value of the fuzzy set, which is a representation of the final result of the fuzzy inference system. The moment is calculated using the integral of the product between the output variable value and the fuzzy set membership function.

$$m_1 = \frac{x - a}{b - a} = \frac{x - 20}{25 - 20} = \frac{x - 0}{5} = 0.2x - 4$$

$$m_2 = 0.33$$

$$m_3 = \frac{c - x}{c - b} = \frac{30 - x}{30 - 5} = \frac{30 - x}{5} = 6 - 0.2x$$

∴ The value of m1 is **0.2x - 4**, m2 is **0.33**, and m3 is **6 - 0.2x**

#### Set moment 1

$$m = \int_a^b F(x)x \cdot dx$$

$$m_1 = \int_{20}^{21.65} (0.2x - 4)x \cdot dx$$

$$m_1 = \int_{20}^{21.65} 0.2x^2 - 4x \cdot dx$$

$$m1 = \int_{20}^{21.65} \frac{0.2x^3}{3} - \frac{4x^2}{2} \rightarrow \int_{20}^{21.65} 0.067x^3 - 2x^2$$

$$m1 = [0.067(21.65)^3 - 2(21.65)^2] - [0.067(20)^3 - 2(20)^2]$$

$$m1 = [679.905 - 937.445] - [536 - 800]$$

$$m1 = -257.54 - (-264)$$

$$m1 = -257.54 + 264 = 6.46$$

∴ The value of m1 is **6.46**

### Set moment 2

$$m = \int_a^b F(x)x \cdot dx$$

$$m2 = \int_{21.65}^{28.35} (0.33)x \cdot dx = 55.27$$

$$m2 = \int_{21.65}^{28.35} 0.165x^2$$

$$m2 = [0.165(28.35)^2 - 0.165(21.65)^2]$$

$$m2 = 132.614 - 77.339 = 55.275$$

∴ The value of m2 is **55.275**

### Set moment 3

$$m = \int_a^b F(x)x \cdot dx$$

$$m3 = \int_{28.35}^{30} (6 - 0.2x)x \cdot dx = 7.86$$

$$m3 = \int_{28.35}^{30} (6 - 0.2x)x \cdot dx \rightarrow \int_{28.35}^{30} 6x - 0.2x^2 \cdot dx$$

$$m3 = \int_{28.35}^{30} \frac{6x^2}{2} - \frac{0.2x^3}{3} \rightarrow \int_{28.35}^{30} 3x^2 - 0.067x^3$$

$$m3 = [3(30)^2 - 0.067(30)^3] - [2(28.35)^2 - 0.067(28.35)^3]$$

$$m3 = [2700 - 1809] - [2411.1675 - 1526,630]$$

$$m3 = 891 - 884.5368 = 6.4632$$

∴ The value of m3 is **6.4632**

### Defuzzyfikasi

$$\frac{m1 + m2 + m3}{ld1 + ld2 + ld2}$$

$$\frac{6.46 + 55.275 + 6.4632}{0.272 + 2.211 + 0.272} = \frac{68.1982}{2.755} = 24.75432 = 24.75 = 25$$

$$\text{Margin error} = 25 - 24.75 = 0.25\%$$

∴ IF the water temperature is 25°C or hot AND the pH level of the water is 6.5 or high then the plant height is tall with **value 24.75** which is rounded up to **25** so that the margin of error is 0.25%.

The results of this calculation are the same as the results of the fuzzy expert system used for the comparison. Comparisons are made to measure the accuracy of the fuzzy rules created. The result of the input water temperature is 25°C or hot AND the pH level of the water is 6.5 or high in the expert system used, MATLAB, for pak choi plant height is equal to 25. The results can be seen in Figure 5 t shown below. The following is an image that shows the output of the fuzzy rules applied according to the input entered.

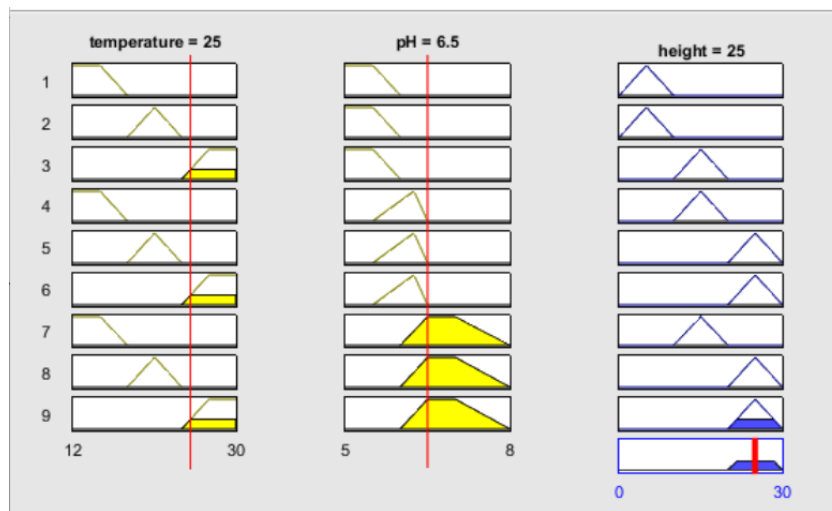


Figure 5. Fuzzy Rules Output

The column on the left shows the water temperature input, the column in the middle shows the water pH level input, and the column on the far right is the column that shows the output or plant height. According to the data tested, the input water temperature column shows 25, the water pH lever shows 6.5 and the plant height output shows 25. The result is in accordance with the manual calculation which is 24.75 which is rounded up to 25 so that the margin of error is 0.25%.

## CONCLUSION

This study explores the potential of fuzzy logic in optimizing hydroponic cultivation of pak choi plants, addressing the need for efficient urban agricultural practices. By analyzing the influence of water pH and temperature on plant growth, a fuzzy expert system based on Mamdani's method was developed. Gathering data on optimal conditions, fuzzy sets were established for water pH, temperature, and plant height using triangular and trapezoidal membership functions. Through fuzzy logic implementation, insights into the effects of pH and temperature on plant growth were gained. The developed system provides a tool for farmers to adjust environmental factors for optimal growth, contributing to advancements in urban farming and sustainable food production. Further research and application of fuzzy logic in agriculture are crucial for maximizing its potential in enhancing plant growth and supporting sustainable farming practices.

## REFERENCES

Caggiano, A. (2019). Fuzzy Logic. CIRP Encyclopedia Of Production Engineering.

- Dani AW. 2020. Optimalisasi Pertumbuhan Pada Sayuran Hidroponik Nutrient Film Technique Dengan Metode Fuzzy Logic Berbasis Internet Of Things. *J Teknol Elektro*. 11(1):1. Doi:10.22441/Jte.2020.V11i1.001.
- Devi N, Erwanto D, Utomo Y. 2018. *Multitek Indonesia : Jurnal Ilmiah Multitek Indonesia : Jurnal Ilmiah*. *Multitek Indones J Ilm*. 12(2):104–113.
- Fathurrahman F, Setiawan E, Fitriyah H. 2023. Sistem Kendali Kekeruhan Dan Ph Media Hidroponik Untuk Selada Air Menggunakan Algoritma Fuzzy. 7(7):3057–3062.
- Fernández, A., & Herrera, F. (2012). *Linguistic Fuzzy Rules In Data Mining: Follow-Up Mamdani Fuzzy Modeling Principle*. Combining Experimentation And Theory.
- Fiqar TP, Fitriani F, Abdullah RK. 2023. Implementasi Sistem Monitoring Tanaman Hidroponik Menggunakan Metode Fuzzy Sugeno. *JTIM J Teknol Inf Dan Multimed*. 5(2):109–121. Doi:10.35746/Jtim.V5i2.372.
- Furhman, J. (2017). *ANDI Food Scores: Rating The Nutrient Density Of Foods*.
- Gerla, G. (2001). *Fuzzy Logic: Mathematical Tools For Approximate Reasoning*.
- Hamdani, M.W. (2022). Perancangan Dan Implementasi Metode Kontrol Fuzzy Logic Mamdani Pada Sistem Kontrol TDS Dan Ph Hidroponik. *JTT (Jurnal Teknologi Terpadu)*.
- Harun, M.U., Sodikin, E., & Wirsawan, H. (2022). Produktivitas Tanaman Pakcoy (Brassica Rapa L) Menggunakan Hidroponik Sistem Rakit Apung. *Publikasi Penelitian Terapan Dan Kebijakan*.
- Huda MS, Suheri H, Nufus NH. 2023. Pengaruh Perbedaan Ph Larutan Hara Terhadap Pertumbuhan Dan Hasil Tanaman Pakcoy Dalam Sistem Hidroponik Nutrient Film Technique (Nft): Agroteksos. 33(1):108. Doi:10.29303/Agroteksos.V33i1.802.
- Iskandar, D., Sapariyah, R.A., & Khristiana, Y. (2021). Budidaya Tanaman Sayuran Secara Hidroponik Di Lahan Pekarangan Bagi Warga Kecamatan Jebres Kota Surakarta. *WASANA NYATA*.
- I Wayan Sukasana, I Nengah Karnata BI. 2019. Dengan Mengatur Dosis Nutrisi Ab Mix Agrifarm Dan Umur Bibit Secara Hidroponik Sistem NFT. 13(2):212–220. [Http://Journal.Unmasmataram.Ac.Id/Index.Php/](http://journal.unmasmataram.ac.id/index.php/).
- Indriani ES, Qurthobi A, Darmawan D. 2020. Design Of Nutrition Temperature Control On Hydroponics System Using Fuzzy Logic Control; Case Study Curly Lattuce (Lactuca Sativa L.). *E-Proceeding Eng*. 7(1):1274–1280.
- Jantzen, J. (2001). *Tutorial On Fuzzy Logic*.
- Kurniati, V., Triyanto, D., & Rismawan, T. (2017). Penerapan Logika Fuzzy Dalam Sistem Prakiraan Cuaca Berbasis Mikrokontroler. *Jurnal Coding, Sistem Komputer Untan*, 5, 119-128.
- Luthfi Andhikaputra M, Faisol A, Auliasari K. 2021. Penerapan Metode Fuzzy Pada Sistem Monitoring Perkembangan Tanaman Hidroponik. *JATI (Jurnal Mhs Tek Inform*. 5(1):299–307. Doi:10.36040/Jati.V5i1.3312.
- Malik A, Hartono R. 2021. Sistem Otomatis Pembuatan Nutrisi Ideal Untuk Tanaman Pakcoy Menggunakan Kendali Logika Fuzzy. *Telekontran J Ilm Telekomun Kendali Dan Elektron Terap*. 9(2):154–164. Doi:10.34010/Telekontran.V9i2.5624.
- Mashumah S, Kumala Pramartaningthyas E. 2022. Sistem Monitoring Tanaman Pakcoy Hidroponik Nutrient Film Technique (Nft) Berbasis Internet Of Things. *Multitek Indones*. 16(1):47–60. Doi:10.24269/Mtkind.V16i1.4342.
- Rahmah F, Hidayanti F, Innah M. 2019. Penerapan Smart Sensor Untuk Kendali Ph Dan Level Larutan Nutrisi Pada Sistem Hidroponik Tanaman Pakcoy. *J Teknol Inf Dan Ilmu Komput*. 6(5):527–534. Doi:10.25126/Jtiik.2019651738.
- Rahmatullah ZU, Irawan D. 2023. Rancang Bangun Alat Perawatan Dan Pemberian Nutrisi Otomatis Pada Tanaman Pakcoy Hidroponik Berbasis Internet Of Things Menggunakan Fuzzy Logic Control Design Of An Automatic Nutrition Treatment And Providing Tool For IoT-Based Hydroponic Pakcoy Plants Us. *Telekontran*. 11(1):63–73.
- Rakhman, A. (2015). Pertumbuhan Tanaman Sawi Menggunakan Sistem Hidroponik Dan Akuaponik.
- Ria M, Asmuliani. 2017. Uji Pertumbuhan Dan Hasil Tanaman Pakcoy (Brassica Rapa L.) Dengan Pemberian Pupuk Organik Cair Pada Sistem Hidroponik. *J AGRIFOR*. 16(1):65–74.
- Rizal S. 2017. Pengaruh Nutrisi Terhadap Perrumbuhan Tanaman Sawi Pakcoy (Brasicca Rapa L.) Yang Di Tanam Secara Hidroponik. *Sainmatika*. 14(1):38–44.

- Saptorini, S., & Sutiknjo, T.D. (2021). Budidaya Tanaman Sayur Dengan Metode Hidroponik Sederhana Dalam Memanfaatkan Botol Bekas Untuk Memenuhi Kebutuhan Pangan Keluarga Dalam Masa Pandemi Covid-19. *Jatimas: Jurnal Pertanian Dan Pengabdian Masyarakat*.
- Suryatini F, Pancono S, Bhaskoro Sb, Muljono Pms. 2021. Sistem Kendali Nutrisi Hidroponik Berbasis Fuzzy Logic Berdasarkan Objek Tanam. *Elkomika J Tek Energi Elektr Tek Telekomun Tek Elektron*. 9(2):263. Doi:10.26760/Elkomika.V9i2.263.
- Suryatini F, Purnomo W, R. Harlanti R. 2023. Sistem Kendali Penyemaian Bersusun Pada Tanaman Hidroponik Berbasis Logika Fuzzy Tsukamoto Dengan Aplikasi Blynk. *JITEL (Jurnal Ilm Telekomun Elektron Dan List Tenaga)*. 3(1):37–46. Doi:10.35313/Jitel.V3.I1.2023.37-46.
- Syarifatul Izza, Gillang Al Azhar, Arianti Kusumawardhani, Novta Dany'el Irawan. 2023. Optimalisasi Pertumbuhan Tanaman Sawo Melalui Pemantauan Kelembapan Tanah Berbasis Iot Dengan Pengendali Fuzzy Logic. *J Elektron dan Otomasi Ind*. 10(3):426–433. Doi:10.33795/Elkolind.V10i3.4420.
- Usman, Harlina, S., & Rizaldy, A. (2019). Rancangan Bangunan Sistem Pengendali Suhu Kelembaban Dan Cahaya Pada Rumah Walet Berbasis Mikrokontroler. *E-Jurnal Jusiti (Jurnal Sistem Informasi Dan Teknologi Informasi)*.
- Yulianto KD, Maududie A, El Maidah N. 2022. Implementasi Metode Fuzzy Sebagai Sistem Kontrol Kepekatan Nutrisi Otomatis Tanaman Hidroponik Berbasis Mikrokontroler Pasa Rangkaian Nutrient Film Technique (NFT). *Informal Informatics J*. 7(1):16. Doi:10.19184/Isj.V7i1.29386.
- Yunus M. 2017. Penerapan Fuzzy Expert System Untuk Diagnosa Penyakit Telinga, Hidung Dan Tenggorokan (THT). *J Matrik*. 15(1):51. Doi:10.30812/Matrik.V15i1.29.
- Zakaria FD, Priyandoko G, Mukhsim M. 2022. Rancang Bangun Sistem Kontrol Untuk Pencampur Nutrisi Hidroponik Metode Pengairan DFT Berbasis Logika Fuzzy. *J Teknol Elektro*. 13(3):171. Doi:10.22441/Jte.2022.V13i3.008.