

Application of Fuzzy Logic to Predict Rice Production Quantity in Bogor Regency

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Abstract

This study aims to understand prediction methods using fuzzy Mamdani logic to conclude the quantity of rice production in the Bogor Regency area. Then in this study, we used quantitative methods and involved interviews with resource persons, namely rice mill workers and farmers. The data obtained from the interview is then fuzzyfication to be used in calculations. The main finding of this study is the elaboration of crop quantity from small, normal, and many, with the range of yields produced ranging from 0 to 3000 KG for little, 3000 to 6000 KG for normal, and 6000 to 10000 KG for many. Weather and humidity observations were found to significantly affect rice yields. The implications of these findings are improved accuracy in yield estimation, and the ability to address uncertainty and complexity in factors affecting crop growth. Despite the limitations of this study, such as limited data and remote study locations, the use of fuzzy logic can make a crucial contribution to determining the quantity of water needed for plant growth based on rainfall and weather conditions. This research is crucial because it can be a reference for future research that uses fuzzy logic to determine the quantity of rice production. In the current context of knowledge, this study fills a gap due to the rare use of fuzzy logic in research related to rice production. The simple implications of this research can help the development of fuzzy logic science that can be applied to agricultural contexts.

Keywords: Agriculture, Fuzzy logic, Observation, Quantity, Rice production

INTRODUCTION

As an agricultural country, Indonesia relies on the success of its farmers to support its food security. Agriculture, especially rice crops that produce rice, plays an important role in improving the welfare of the Indonesian population (Indra, 2016). Agriculture is important for the development of a country, especially for developing countries, including Indonesia. Activities in the agricultural sector ensure the survival of the surrounding community, provide employment, and provide local food (Sahri *et al.* 2022). Rice production is the amount of rice produced from cultivated agricultural land during one growing season and is measured in kilograms (kg) (Ismi *et al.*, 2023).

Successful increase in production can only be achieved by mobilizing all available resources, both through existing conditions and through innovative strategies and policies to take advantage of new possibilities. Providing facilitation and support to economic actors (farmers) is one of the strategic steps to achieve production goals (Purwantini and Susilowati 2018). Rice production factors in general are soil, temperature, rainfall, and water resources while auxiliary production factors are the use of fertilizers, drugs, and management systems that have a significant influence on rice production (Fallo *et al.*, 2018). Agricultural production, especially rice, is strongly influenced by the inputs used in the production process. The inputs used are fertilizers, pesticides, seeds, mechanization with fuel oil, and irrigation. These inputs can come from synthetic or organic materials depending on the function and

risk. In general, inputs from synthesis change yields faster than inputs from organic sources, but can cause long-term degradation of land resources (Santoso, 2015).

Rice fields are land that is used or has the potential to be planted with rice fields. In this definition, rice fields include all land located in a climatic zone with temperature conditions suitable for rice cultivation at least once a year (availability of water to flood the soil during rice processing). Therefore, temperature and water become the main limitations (Fallo *et al.*, 2018). The availability of land for agricultural expansion is one of the key factors in maintaining food self-sufficiency and has succeeded in making Indonesia the world's food granary by 2045 (Sumantri *et al.* 2021).

Rainfall is one of the climate variables that has a significant impact on rice productivity in Indonesia. Increased rainfall has a positive impact to a certain point, but beyond a certain point, an increase in rainfall has a negative impact on rice productivity (Sumantri *et al.*, 2021). Rice tends to be resistant to high temperatures during the vegetative phase, but sensitive during the reproductive phase. High temperatures before and during flowering reduce the fertility of plant pollen. Exposing rice to high temperatures above 33.7 °C for 1 hour during flowering can affect fertility (Usama Jaisyurahman *et al.*, 2020). Because water needs are very important for the growth of food crops in rainfed areas, the contribution of water from reservoirs plays an important role in ensuring crop yields. The amount of rainwater required by rice paddy fields in rainfed areas is 183–366 mm/month, taking into account the average evapotranspiration of about 3–7 mm/day and the average infiltration rate of 1–2 mm/day. The lower limit of rainwater requirements for paddy fields is > 200 mm/day (Wihardjaka *et al.*, 2020).

With an area of 1,905,000 km² and is on the equator. Most areas are in the southern hemisphere and some are in the northern hemisphere. Indonesia is located in the middle of the Indian Ocean and the Pacific Ocean. This causes the weather to change in Indonesia. The amount of rainfall that falls each year changes due to monsoon winds, which change once every six months. According to the type of rainfall in Indonesia, there are at least five different seasonal patterns, which can be simplified into three types (Aldrian *et al.*, 2016). Differences in seasonal patterns affect cropping patterns in each region, leading to differences in cropping indexes, ultimately affecting rice production in each state. When developing rice production as food, the diversity of climatic conditions must be considered (Santoso *et al.*, 2022).

Fuzzy logic is logic that can be used to analyze problems involving uncertainty. An example is the prediction process (Rahman and Yanti 2023). Professor Lutfi A. Zadeh, a computer science researcher at the University of California, Berkeley, first developed fuzzy logic in 1965, because he believed that right and wrong logic could not describe the entire human thought. After that, Professor Zadeh developed fuzzy logic, which can describe any human situation or thought. In strict logic, there are two possibilities that an element exists in a set or has a value of 1, which means true; In fuzzy logic, there is no possibility that an element exists in the set or has a value of 0, which means false. Instead, element membership occurs periodically in fuzzy logic (Rahmawati *et al.*, 2020).

Based on the problems that have been discussed regarding the quantity of rice production in the Bogor district, fuzzy logic calculations are used using the Mamdani method. The Mamdani method is also called the Max-Min method. This method was introduced by Ebrahim Mamdani in 1975. If translated according to vocabulary, fuzzy means ambiguous and logic means inference. So, if summarized in one word, it means an unclear reason (Putri and Maulana 2023).

METHOD

The study was conducted for three months from January to April. The research locations are Sukanegara Village, Jonggol District, Bogor Regency and the IPB Vocational School Computer Lab. Facilities available at the site include academic journals, reference books, related scientific publications that support rice production prediction research, and interviews with rice collectors in Sukanegara Village.

1. Research Methods

The image below is a flowchart to determine the quantity of rice produced. Inputs to determine the quantity, namely air temperature and weather such as rainfall to then get output in the form of little, normal and the amount of rice produced.

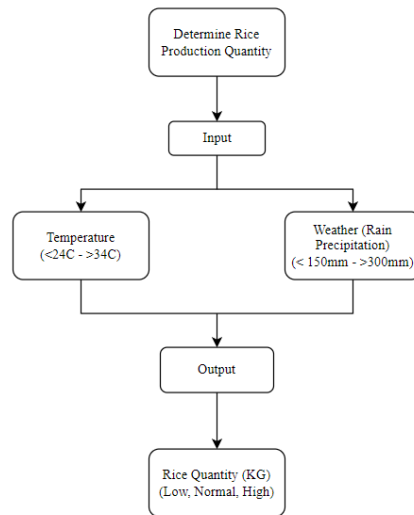


Figure 1. Flowchart to determine Rice Production Quantity

This study uses a quantitative approach, which centers on the application of fuzzy logic to determine rice production. The quantitative approach involves the process of research, hypothesis or prediction of results, empirical data, data analysis, and data conclusion. The quantitative approach uses measurements, calculations, formulas, numerical data aspects, or statistical calculations to show the final result (Rukminingsih et al., 2020). Thus, it can be said that quantitative descriptive methods were used to conduct this research survey. This study aims to interview rice farmers in a particular region and conduct literature research based on experts. An expert system is a method that combines knowledge, facts, and search techniques to solve problems that usually require expert expertise. Therefore, fuzzy logic is needed in the process of its implementation. Fuzzy logic is very flexible and can adapt to changes that occur and uncertainty related to problems (Apriliana et al., 2020).

2. Data Collection Techniques

This research was conducted by applying a fuzzy logic system to rice production prediction data which includes input variables such as air temperature and rainfall. The stages in collecting data in this study are as follows:

1. Interview

An interview can simply be defined as an event or process of interaction between the interviewer and the interviewee through direct communication (Yusuf, 2014). The purpose of the interview is to gain an in-depth understanding of the experience, views, and perspectives of individuals regarding the phenomenon under study depending on the level of a particular framework. The interview can be structured, semi-structured, or unstructured (Jailani M. S, 2023).



Figure 2. Interviewing the Source

Interviews with rice collectors revealed that farmers cannot plant rice if there is little rainfall. When rainfall is small, there is almost no rice left, and because the rice is imported from abroad, the amount of rice produced is only about 2 tons.

2. Literature Studies

Literature studies are research that utilizes data by reading, recording, and processing library data without conducting research directly (Effendi and Reinita 2020). This type of research is literature research (Pusparani, 2021). This research is a quantitative research based on a literature review. The research phase is carried out through the collection of primary and secondary library materials. This study classifies data based on research formulations at an advanced stage, data processing and references are cited and presented as research results, abstracted to obtain complete information, and interpreted to gain insight in drawing conclusions (Darmalaksana, 2020). Based on data from the Meteorology, Climatology, and Geophysics Agency, climatological analysis is conducted to determine the range of rainfall occurring in Indonesia.

Table 1. Rain Precipitation Data according to BMKG

| No | Frequency | Class |
|----|--------------|--------|
| 1. | 27 – 175 mm | Low |
| 2. | 150 – 300 mm | Normal |
| 3. | 280 – 430 mm | High |

BMKG has various types of automatic monitoring tools: AWS (Automatic Weather Station), AAWS (Agroclimate Automatic Weather Station), and ARG (Automatic Rain Gauge). This automated observation tool has one or more sensors and generates data such as air temperature, relative humidity, wind direction and speed, solar radiation intensity, air pressure and precipitation, soil temperature, and soil moisture (Alfiandy *et al.* 2020).

Then there is air temperature data from the Central Static Agency which conducts an agricultural census with a data collection method that counts all farmers, agricultural households, and agricultural businesses in the territory of the Unitary State of the Republic of Indonesia and obtains the characteristics of agricultural businesses at a certain time (Badan Pusat Statistik, 2018)

Table 2. Temperature Data according to BMKG

| No | Frequency | Class |
|----|-------------|--------|
| 1. | 21°C – 25°C | Low |
| 2. | 24°C – 28°C | Normal |

3. Data Analysis

When raw data is analyzed and interpreted, they become significant. Therefore, data analysis is very important for research. Organizing, categorizing, grouping, coding, and classifying them is the task of data analysis in this regard. The purpose of organizing and managing data is to identify working themes and hypotheses that will ultimately lead to the formation of substantive theories. As a result, data analysis is very important because it can provide meaning and significance to data to help research questions (Siregar, 2021).

In addition, the study includes several stages: initial data collection, fuzzy model creation, and application of the model in decision-making. Next, the data was analyzed using fuzzy logic programs that were used for research needs. After data collection, one of the research activities is data processing. According to Sabri (2019), initial data must be processed to produce information that can be used to answer research objectives. To improve accuracy in determining rice production, this study used quantitative methods and fuzzy logic techniques. Matlab is a high-level programming language developed by MathWorks specifically for numerical computation, visualization, and programming. Matlab allows users to perform data analysis, develop algorithms, and build models and applications (Parinduri 2018). Matlab provides a special toolbox for fuzzy logic called the Fuzzy Logic Toolbox. This toolbox provides functions for creating, editing, and testing fuzzy inference systems. The Fuzzy Logic Toolbox in Matlab enables users to create complex fuzzy inference systems (Subarja and Hendrik 2023). The stages of developing a fuzzy logic optimization model include:

1. Data Fuzzification

Data fuzzification is the process of changing quantitative data into fuzzy sets or sets with membership values that change at certain intervals. Temperature, Rain Precipitation, and humidity are examples of quantitative values that are converted into fuzzy set membership values, which are very helpful in modeling uncertain or incomplete data, thereby enabling better decision-making in various applications (Siregar et al., 2023).

2. Membership Functions

The membership function is a curve that shows the mapping of input data points to membership values (also called membership degrees) which range from 0 to 1 (Ismail et al., 2015). The function approach is one method that can be used to obtain membership values (Muchammad Abrori and Amrul Hinung Prihamayu 2015). Several functions can be used including:

1. Linear Representation
2. Triangular Curve Representation
3. Trapezoidal Curve Representation
4. Sump Shape Curve Representation

3. Inference Fuzzy

The fuzzy inference system is a computational framework based on fuzzy set theory, fuzzy rules in the form of IF-THEN, and fuzzy reasoning. There are three methods of fuzzy argument reason, the Mamdani Method, the Tsukamoto Method, and the Sugeno Method. Fuzzy inference is used as a tool to represent different knowledge about a problem and to model the interactions and relationships that exist between these variables (Athiyah et al., 2021). Each rule result in the form of IF AND THEN must be represented in fuzzy sets using monotonically increasing membership functions. The output of the inference result from each rule is given

clearly (crisp) based on the predicate α (fire strength), and the final result is determined using the average (Hendiyani and Sugiyarto 2019).

4. Defuzzification

Defuzzification can be defined as the process of modifying fuzzy quantities expressed in the form of output fuzzy sets using membership functions to regain a well-defined form. This is necessary because real-world applications require explicit values. The process goes like this: The fuzzy output values from the rule evaluation are taken and fed into the membership function output. These values are fed into the defuzzification method, which produces a final result called crisp output. Defuzzification is the final step in a fuzzy logic control system, and its goal is to convert each inference engine result, expressed in the form of a fuzzy set, into a real number. The results of this transformation are actions carried out by the fuzzy logic control system. Therefore, choosing the right defuzzification method also influences the fuzzy logic control system in producing an optimal response (Siregar et al., 2023).

RESULTS AND DISCUSSION

In the results and discussion section, we will discuss the influence of the quantity of rice produced using data collected from BMKG (Meteorology, Climatology, and Geophysics Agency) as well as informants involved in rice cultivation. Below is the flowchart for the quantity of rice produced along with its application in MATLAB software.

We have three variables: two input variables, Temperature and Rain Precipitation, and one output variable, the quantity of rice production. We'll be using the MIN implication function, which intersects the output at the height of the function corresponding to the assumption, thereby obtaining the minimum membership value among the elements in the problem set. Our focus is on the output variable, 'Quantity', determined by the Temperature and Rain Precipitation inputs. We'll employ the Mamdani method along with specific rules to explain the formula and generate the output.

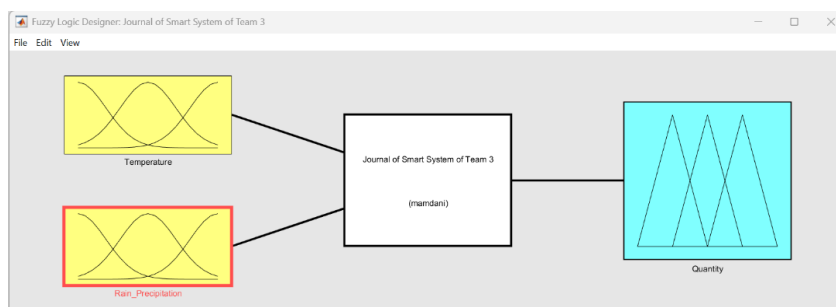


Figure 3. Fuzzy Logic Design using the Mamdani Method

Membership Function in Determining the Production Quantity of Rice Products

The image below shows the membership functions of the Temperature input variable. The Temperature variable is created with a Trapezoidal type with a range of 20°C to 35°C. The linguistic variables used for the Temperature input are Minimum, Normal, and Maximum. The parameter values for Minimum are from 21°C to 25°C, with the peak points at 22°C to 23°C. The parameter values for Normal are from 24°C to 28°C, with the peak points at 25°C to 26°C. Lastly, the parameter values for Maximum are from 27°C to 31°C, with the peak points at 28°C to 29°C.

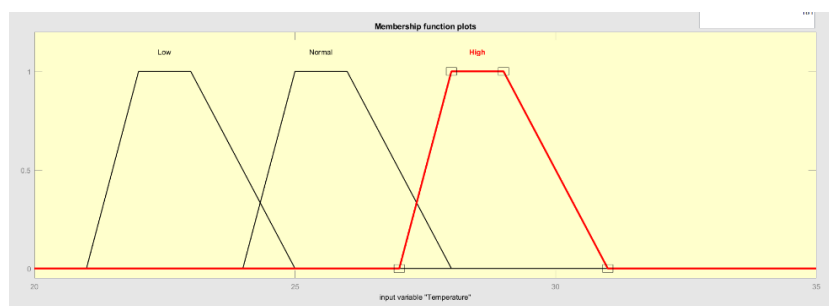


Figure 4. Fuzzy Membership Levels for the Input 'Temperature'.

Then the membership function on the input Rain Precipitation. Rain Precipitation is made with Trapezoidal type with a range of 0 – 400 mm. The linguistic variables used in Rain Precipitation inputs are Low, Normal, and Heavy. The value of the Low parameter is 27 – 175 mm with a peak point of 50 – 100 mm. Then the value of the Normal parameter is 150 – 300 mm with a peak point of 175 – 225 mm. Finally, the value of the Heavy parameter is 280 – 430 mm with a peak point of 305 – 355 mm.

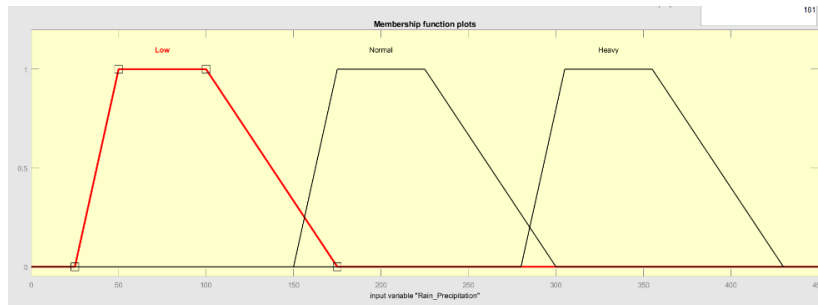


Figure 5. Fuzzy Membership Levels for the Input “Rain Precipitation”.

In the picture below there is a membership function for the output variable Quantity. Variable Rain Precipitation is made in the Trapezoid type with a range of 0 – 10,000kg. The linguistic variables used in the Quantity output are Little, Medium, and Lots. The Slight parameter value is 0 – 3,000kg with a peak point of 1,000 – 2,000kg. Then the Normal parameter value is 3,000 – 6,000kg with a peak point of 4,000 – 5000kg. The final value of the Plenty parameter is 6,000 – 10,000kg with a peak point of 7,000kg.

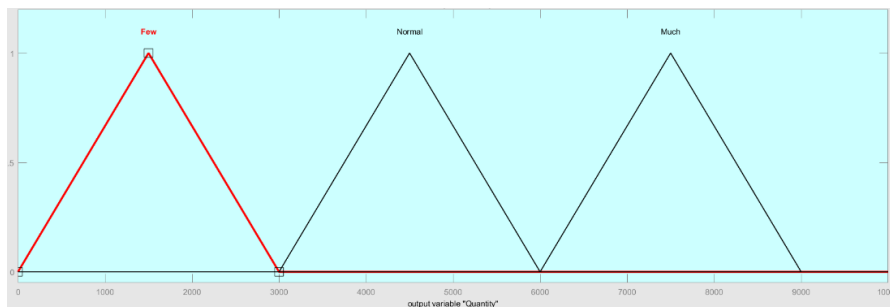


Figure 6. Fuzzy Membership Levels for the Output 'Quantity'.

Membership Association

Fuzzy logic has membership sets. This membership set is determined through literature reviews or interviews with experts. From the results of interviews with resource persons, a range was obtained for each parameter for each variable, and then calculations carried out will be explained as follows:

Trapezoid Formula :

$$F(X) = \left\{ \begin{array}{l} 0, \quad x \leq a \\ \frac{x-a}{b-a}, \quad a \leq x \leq b \\ 1, \quad b \leq x \leq c \\ \frac{d-x}{d-c}, \quad c \leq x \leq d \\ 0, \quad d \leq x \end{array} \right.$$

Triangle Formula :

$$F(X) = \left\{ \begin{array}{l} 0, \quad x \leq a \\ \frac{x-a}{b-a}, \quad a \leq x \leq b \\ \frac{c-x}{c-b}, \quad b \leq x \leq c \\ 0, \quad d \leq x \end{array} \right.$$

$$\begin{aligned}
F(\text{Temperature}) &= \{\mu_{\text{Low}}(x)\{0 \text{ if } x \leq 21 \frac{x-21}{22-21} \text{ if } 21 \leq x \\
&\leq 22 \frac{1 \text{ if } 22 \leq x \leq 23 \frac{25-x}{25-23} \text{ if } 23 \leq x \leq 25}{0 \text{ if } x \geq 25} \mu_{\text{Normal}}(x)\{0 \text{ if } x \\
&\leq 24 \frac{x-24}{25-24} \text{ if } 24 \leq x \\
&\leq 25 \frac{1 \text{ if } 25 \leq x \leq 26 \frac{28-x}{28-26} \text{ if } 26 \leq x \leq 28}{0 \text{ if } x \geq 28} \mu_{\text{High}}(x)\{0 \text{ if } x \\
&\leq 27 \frac{x-27}{28-27} \text{ if } 27 \leq x \leq 28 \frac{1 \text{ if } 28 \leq x \leq 29 \frac{31-x}{31-29} \text{ if } 29 \leq x \leq 31}{0 \text{ if } x \geq 31}
\end{aligned}$$

$$\begin{aligned}
F(\text{Rain_Precipitation}) &= \{\mu_{\text{Low}}(x)\{0 \text{ if } x \leq 25 \frac{x-25}{50-25} \text{ if } 25 \leq x \\
&\leq 50 \frac{1 \text{ if } 50 \leq x \leq 100 \frac{175-x}{175-100} \text{ if } 100 \leq x \leq 175}{0 \text{ if } x \geq 175} \mu_{\text{Normal}}(x)\{0 \text{ if } x \\
&\leq 150 \frac{x-150}{175-150} \text{ if } 150 \leq x \\
&\leq 175 \frac{1 \text{ if } 175 \leq x \leq 225 \frac{300-x}{300-225} \text{ if } 225 \leq x \leq 300}{0 \text{ if } x \geq 300} \mu_{\text{High}}(x)\{0 \text{ if } x \\
&\leq 280 \frac{x-280}{305-280} \text{ if } 280 \leq x \\
&\leq 305 \frac{1 \text{ if } 305 \leq x \leq 355 \frac{430-x}{430-355} \text{ if } 355 \leq x \leq 430}{0 \text{ if } x \geq 430}
\end{aligned}$$

Membership Functions

1. Temperature membership

- Low Temperature (21-25 degrees Celsius) has a membership level $\mu_{\text{Low}}(x)$, a linear function as follows:

$$\mu_{\text{Low}}(x)\{0 \text{ if } x \leq 21 \frac{x-21}{22-21} \text{ if } 21 \leq x \leq 22 \frac{1 \text{ if } 22 \leq x \leq 23 \frac{25-x}{25-23} \text{ if } 23 \leq x \leq 25}{0 \text{ if } x \geq 25}$$

Calculation Example:

$$\mu_{\text{Low}}(21) = \frac{23-21}{25-21} = \frac{2}{4} = 0.5$$

- Normal Temperature (24-28 degrees Celsius) has a membership level $\mu_{\text{Normal}}(x)$, a linear function as follows:

$$\begin{aligned}
\mu_{\text{Normal}}(x)\{0 \text{ if } x \leq 24 \frac{x-24}{25-24} \text{ if } 24 \leq x \\
\leq 25 \frac{1 \text{ if } 25 \leq x \leq 26 \frac{28-x}{28-26} \text{ if } 26 \leq x \leq 28}{0 \text{ if } x \geq 28}
\end{aligned}$$

Calculation Example:

$$\mu_{\text{Normal}}(25) = 1$$

- High Temperature (27-31 degrees Celsius) has a membership level of $\mu_{\text{High}}(x)$, a linear function as follows:

$$\mu_{\text{High}}(x)\{0 \text{ if } x \leq 27 \frac{x-27}{28-27} \text{ if } 27 \leq x \leq 28 \frac{1 \text{ if } 28 \leq x \leq 29 \frac{31-x}{31-29} \text{ if } 29 \leq x \leq 31}{0 \text{ if } x \geq 31}$$

Calculation Example:

$$\mu_{Low}(30) = \frac{31 - 30}{31 - 29} = \frac{1}{2} = 0.5$$

Calculation for $f(\text{temperature})$:

- A low Temperature of 21.5 degrees Celsius in the range of 21 to 25 degrees Celsius has a membership level $\mu_{Low}(x)$ of 0.5
- Normal Temperatures of 25 degrees Celsius which are in the range of 24 to 28 degrees Celsius have a membership level of $\mu_{Normal}(x)$ of 1 because where the Temperature is 25 makes the number $125 \leq x \leq 26$
- High Temperatures of 30 degrees Celsius in the range of 27 to 31 degrees Celsius have a membership level $\mu_{High}(x)$ of 0.5

1. Rain Precipitation Membership

- Low Rain Precipitation (25-175):

$$\mu_{Low}(x) = \begin{cases} 0 & \text{if } x \leq 25 \\ \frac{x - 25}{50 - 25} & \text{if } 25 \leq x \leq 50 \\ 1 & \text{if } 50 \leq x \leq 100 \\ \frac{175 - x}{175 - 100} & \text{if } 100 \leq x \leq 175 \\ 0 & \text{if } x \geq 175 \end{cases}$$

Calculation Example:

$$\mu_{Low}(37\text{mm}) = \frac{37 - 25}{50 - 25} = \frac{12}{25} = 0.48$$

- Normal Rain Precipitation (150-300):

$$\mu_{Normal}(x) = \begin{cases} 0 & \text{if } x \leq 150 \\ \frac{x - 150}{175 - 150} & \text{if } 150 \leq x \leq 175 \\ 1 & \text{if } 175 \leq x \leq 225 \\ \frac{300 - x}{300 - 225} & \text{if } 225 \leq x \leq 300 \\ 0 & \text{if } x \geq 300 \end{cases}$$

Calculation Example:

$$\mu_{Normal}(180\text{mm}) = 1$$

- High Rain Precipitation (280-430)

$$\mu_{High}(x) = \begin{cases} 0 & \text{if } x \leq 280 \\ \frac{x - 280}{305 - 280} & \text{if } 280 \leq x \leq 305 \\ 1 & \text{if } 305 \leq x \leq 355 \\ \frac{430 - x}{430 - 355} & \text{if } 355 \leq x \leq 430 \\ 0 & \text{if } x \geq 430 \end{cases}$$

Calculation Example:

$$\mu_{High}(392\text{mm}) = \frac{430 - 392}{430 - 355} = \frac{38}{75} = 0.5$$

For $f(\text{Rain Precipitation})$:

- 37mm Low Rain Precipitation in the range of 25mm to 50mm has a $\mu_{Low}(x)$ membership level of 0.48 or equal to 0.5
- Normal Rain Precipitation of 180mm which is in the range of 175mm to 225mm has a membership level of $\mu_{Normal}(x)$ of 1
- High Rain Precipitation 392mm which is in the range of 355mm to 430mm has a membership level $\mu_{High}(x)$ of 0.5

Establishment of basic rules

After determining the input and output variables used, the next stage is to determine the rules that determine the output of fuzzification.

Figure 3. Fuzzy Rule-Based

| No | Temperature | Operand | Rain Precipitation | Quantity |
|----|-------------|---------|--------------------|----------|
| 1. | Low | OR | Low | Normal |
| 2. | Low | OR | Normal | Normal |
| 3. | Low | OR | High | Little |
| 4. | Normal | OR | Low | Normal |
| 5. | Normal | OR | Normal | Much |
| 6. | Normal | OR | High | Little |
| 7. | High | OR | Low | Normal |
| 8. | High | OR | Normal | Much |
| 9. | High | OR | High | Little |

Based on the fuzzy rule-based, conditions are used where:

Temperature **28°C** (High) or Rain Precipitation **100mm** (Low) which falls under the 7th rule "IF **Temperature** is **High** or **Precipitation** is **Low** then **Quantity** is **Normal**"

$$\mu_{TempHigh}(x) = \begin{cases} 0 & \text{if } x \leq 27 \\ \frac{x-27}{28-27} & \text{if } 27 \leq x \leq 28 \\ 1 & \text{if } 28 \leq x \leq 29 \\ \frac{31-x}{31-29} & \text{if } 29 \leq x \leq 31 \\ 0 & \text{if } x \geq 31 \end{cases}$$

$$\mu_{Rain_PrecipitationLow}(x) = \begin{cases} 0 & \text{if } x \leq 25 \\ \frac{x-25}{50-25} & \text{if } 25 \leq x \leq 50 \\ 1 & \text{if } 50 \leq x \leq 100 \\ \frac{175-x}{175-100} & \text{if } 100 \leq x \leq 175 \\ 0 & \text{if } x \geq 175 \end{cases}$$

From these rules, the membership degree will be calculated for both conditions:

- Membership degree Maximum Temperature = 1
- Low Rain Precipitation membership degree = 1

Next, use the OR operator to combine the membership degrees of the two conditions, Because the rule uses the OR operator, then use the largest membership degree value of 1:

$$\alpha = \max(1, 1) = 1$$

Next, specify the output value by using the membership degree $\alpha = 1$ on the output graph. In this case, since the value of α is 1, then the selected output is a Normal quantity. The formula for calculating the α value in the rule is:

$$\alpha = \max(\mu(\text{Maximum Temp}), \mu(\text{Low Rain Precipitation}))$$

In this example, the α result is 1 because the largest membership degree is 1. This illustrates how to use the fuzzy rule to determine rice production rates based on Temperature and Rain Precipitation conditions.

Defuzzification

In this defuzzification process. After running the logical results from OR for the input. So we get α of 1. So can be used as the membership height in the Output Curve. So to find the defuzzification results, area and moment are needed. To calculate area area. So the formula is to calculate the area affected by the logical results. Here the output curve that is affected is the Normal curve which is on the threshold of 3000 to 6000. Because the curve used for the output is a triangle, use the Triangle Area formula.

Output function membership set:

Here is the Membership Set of Output Functions in the "Normal" Quantity Section:

$$F(X) = \left\{ \begin{array}{l} 0, \quad x \leq 3000 \\ \frac{x - 3000}{4500 - 3000}, \quad 3000 \leq x \leq 4500 \\ \frac{6000 - x}{6000 - 4500}, \quad 4500 \leq x \leq 6000 \\ 0, \quad 6000 \leq x \end{array} \right\}$$

Here's the calculation:

$$Area = \frac{1}{2}(c - a) \times t$$

$$Area = \frac{1}{2}(6000 - 3000) \times 1$$

$$Area = \frac{1}{2}(3000) = 1500$$

$$Area = 1500$$

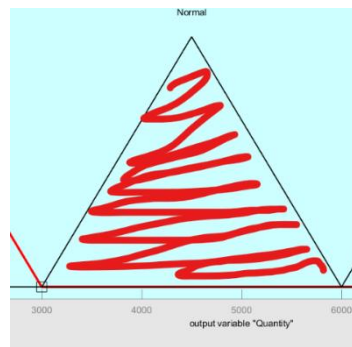


Figure 7. Output Variable "Quantity"

So, the area controlled is 1500. Then the result of the area that has been calculated can be used for Z calculation*.

Calculating Moment

$$F(X) = \left\{ \begin{array}{l} \frac{x - 3000}{1500} = (0.000667x - 2), \quad 3000 \leq x \leq 4500 \\ \frac{6000 - x}{1500} = (4 - 0.000667x), \quad 4500 \leq x \leq 6000 \end{array} \right\}$$

To find out the moments is at each point on the left side of the triangle and the right side of the triangle in the Normal Triangle in the Output Curve. So decimalization is mandatory. After decimalizing the function. So this number is used in calculations.

$$M1 = \int_{3000}^{4500} \frac{x - 3000}{1500} z dz = 3.007.125$$

$$M2 = \int_{4500}^{6000} \frac{6000 - x}{1500} z dz = 3.736.125$$

$$M1 = \int_{3000}^{4500} (0.000667z - 2)z dz = 3.007.125$$

$$M2 = \int_{4500}^{6000} (4 - 0.000667z)z dz = 3.736.125$$

After the Moment is determined. Then this moment will be calculated to find the Crisp/Centroid value. By using the Centroid Formula:

$$Z^* = \frac{M1+M2}{Area}$$

$$Z^* = \frac{3.007.125+3.736.125}{1500}$$

$$Z^* = \frac{6.743.250}{1500}$$

$$Z^* = 4.495,5 \approx 4.5\text{ton} = 4500\text{kg}$$

Based on the results of defuzzification calculations, a final value of 4.5 tons or 4,500 kg was obtained in the prediction of rice production using the fuzzy Mamdani method. Based on the calculation results, if the Temperature reaches 28°C with a Rain Precipitation level of around 100 mm, the quantity of rice produced is 4,500 kg.

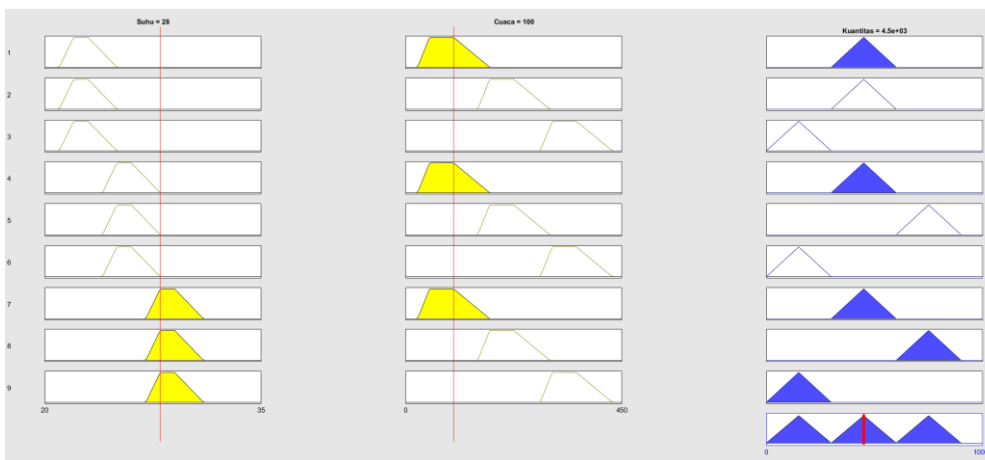


Figure 8. Matlab Rules Output

In the picture above. You can see the calculations from MATLAB where the Temperature is 28C and the Rain Precipitation is 100mm. So the quality will be 4.5e+03 or 4500. So it can be concluded that the result from Z is 4,495.5 then the result from Matlab is 4500 which has an accuracy of 99.99% accuracy. This shows that the manual calculation based on the moment and area determined worked well and the research was completed.

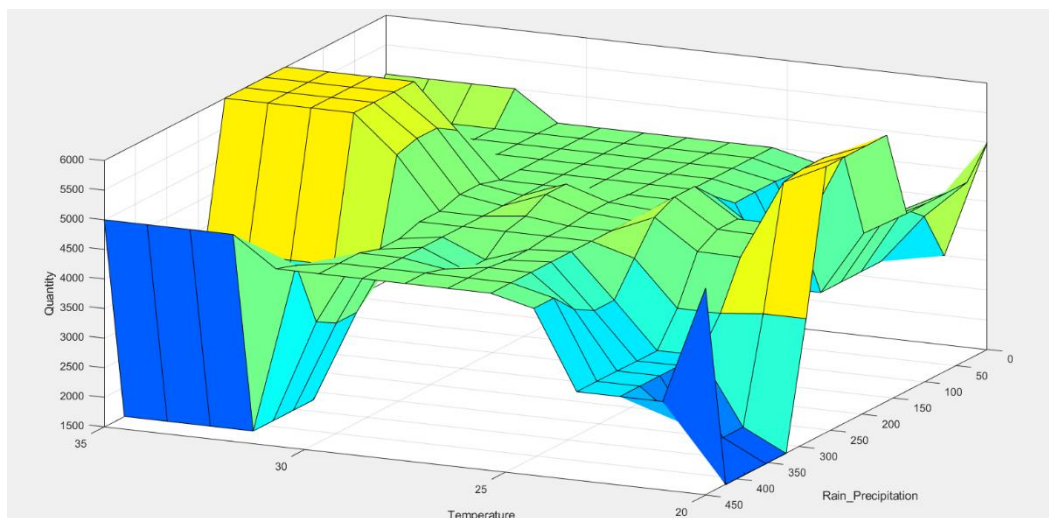


Figure 9. Surface Result from the Rules Created

In the last figure, you can see that this is the surface result based on the Logic Operations that we created. You can see a lot of fluctuations on the graph because the Rain Precipitation and

Temperature factors are mixed. Therefore, the best production is obtained where the Rain Precipitation is between 150 and 250mm. Then you can get maximum production results.

CONCLUSION

The purpose of this study was to predict rice production in Bogor Regency, Indonesia, using fuzzy logic and the Mamdani technique. As an agricultural country, the welfare of the Indonesian people depends on rice production. Rice production affects national food security in addition to being a source of income for farmers. Several factors, such as soil conditions, temperature, Rain Precipitation, and water availability, affect rice production; These parameters determine the yield. In addition, supporting factors such as the use of fertilizers, chemicals, and management systems are also very important to increase agricultural productivity. In this study, fuzzy logic, created by Professor Lutfi A. Zadeh in 1965, was used to analyze uncertainty and complexity in rice production predictions. One method of fuzzy logic, the Mamdani method, is used to apply fuzzy logic when determining rice production. This study was conducted at IPB Vocational School and Sukanegara Village, Bogor Regency, for three months. Data was collected through interviews with farmers, literature reviews, and field observations. A literature review was conducted to gain an understanding of the factors affecting rice production. Meanwhile, interviews were conducted to gain a direct understanding of the farmers.

In this fuzzy logic model, temperature and precipitation are used as input variables, and quantity of rice production is used as output variables. Temperatures are divided into low, normal, and high categories, while precipitation is divided into low, normal, and high categories. Predefined fuzzy rules are used to perform fuzzy inference after the establishment of a membership function. These rules relate input conditions to outputs based on predefined conditions. The Mamdani method combines these rules and produces the quantity of rice production. This research produces a fuzzy logic model that can be used to predict rice production in Bogor Regency based on temperature and Rain Precipitation conditions. This model can provide quantitative estimates of rice production with an acceptable level of accuracy. In conclusion, this study shows that fuzzy logic, especially the Mamdani approach, can be used to predict rice production with a sufficient degree of accuracy. The effectiveness and overall productivity of agriculture can be improved by using fuzzy logic in agricultural analysis.

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