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Optimization of Cassava Production Management using Fuzzy Logic to Enhance Efficiency and Production Yield

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Abstract

This research aims to optimize cassava production using fuzzy logic to enhance efficiency and productivity. Cassava is an important agricultural crop in Indonesia with great potential due to its ability to thrive in various types of soil and climates. Despite being considered a secondary food, cassava has numerous health benefits and serves as a good source of energy. However, crop failures and low yields hinder cassava production. Farmers can achieve optimal yields by maximizing output with minimal input costs. In addition to meeting market demand, pricing strategies are also crucial in determining the best products. Therefore, manufacturing companies need to plan the quantity of products to meet the expected demand. Factors such as product supply and demand need to be considered. It is challenging to monitor production elements when manual calculations are used. Hence, a method to accurately predict product availability is needed. The method used is fuzzy logic computation. We employ the Mamdani fuzzy logic method in this study. The outcome of this research is the ability to enhance cassava production yields based on Mamdani fuzzy logic calculations. The computations conducted enable farmers to determine production levels based on consumer demand.

Keywords: Cassava Production, Optimization, Mamdani Fuzzy Logic, Efficiency, Decision-Making.

INTRODUCTION

Human life is constantly confronted with various problems, including in the realm of business. Humans engage in various types of businesses to meet their needs, both on a local and global scale. With the advancement of time, the business world continues to evolve and become more modern. The goal of these businesses is to achieve profit. One crucial aspect of business is the industry, whether in the production of goods or the provision of services (Khoiruddin, 2011).

Currently, almost all industrial companies face highly competitive challenges. This drives companies to plan and determine the right amount of production to meet market demand at the required time and quantity. Thus, it is expected that companies can achieve optimal profits (Djunaidi et al., 2005).

To maximize profits, companies sell as many products as possible. This means the company must be able to meet all existing demands. If production is less than demand, the company will miss the opportunity to maximize profits. On the other hand, if production exceeds demand, the company will incur losses. Therefore, proper production planning is crucial to ensure that the company can meet market demand effectively. Some factors to consider in determining the amount of production include remaining inventory from previous periods and estimated demand for the next period (Haryati, 2011).

Production is a process in which inputs are transformed into outputs, to increase the value of a good or service. This involves the utilization of production factors as part of the input in that activity. Production factors refer to the relationship between the amount of input and output in a specific period. This concept illustrates the behavior of producers in their effort to maximize profits through the optimal use of a combination of production factors and production functions (Damayanti, 2020).

Cassava is one of the vital agricultural commodities in Indonesia. With ample land area and a suitable tropical climate, Indonesia is an optimal location for cultivating cassava (Purnomo & Kusuma, 2022). The uniqueness of this plant lies in its ability to thrive in both high and lowlands without being affected by seasons. Traditionally considered as an inferior food, cassava holds significant untapped potential. Despite often being viewed as a secondary food choice after staple foods like rice, cassava possesses remarkable health benefits and potential as a valuable energy source. It contains approximately 38 grams of carbohydrates per 100 grams, equivalent to 12%, making it a suitable alternative to rice in dietary consumption (Sosial et al., n.d.). Cassava contains 100-150 calories per 100 grams, higher than some other tubers (Risky Siregar Program Ilmu Kesehatan Masyarakat et al., 2023). Moreover, cassava is rich in fiber and complex carbohydrates, providing positive benefits for digestive health and blood sugar regulation. With a low glycemic index, cassava can also serve as an antioxidant source, making it a good food choice to support health.

The availability of carbohydrate sources in food is crucial to meet the needs of the community. The government continues to make efforts through programs to increase local carbohydrate sources other than rice. Data from the Indonesian Central Statistics Agency (BPS) in 2019 indicates that cassava consumption has steadily increased from 2015 to 2019, with a growth rate of 14.84% annually. Cassava has significant potential to be developed as a food source, animal feed, as well as raw material for industries and their derivative products. Demand for cassava increases by approximately 30-35% annually, indicating significant business opportunities for farmers and entrepreneurs to meet the demand for cassava (Yusya Abubakar et al., 2021).

In 2020, Indonesia's cassava production reached 27.3 million tons, making it the fourth largest food crop commodity after rice, corn, and sweet potatoes. However, cassava production in Indonesia is still hindered by inefficiency and low yields. The average cassava yield in Indonesia is only about 20 tons per hectare, far below its potential yield of 40 tons per hectare. One of the factors contributing to inefficiency and low cassava yields is the lack of optimal production management. Farmers often use traditional methods that are neither precise nor adaptive to environmental changes (Eka N, 2022).

The low cassava production in Indonesia is attributed to various interrelated factors. Firstly, there is a lack of knowledge and skills among farmers in implementing optimal cultivation methods (Maghfiroh & Nuswardhani, 2019). This is evident from the excessive use of fertilizers and pesticides, inappropriate selection of varieties for environmental conditions, and incorrect timing of planting. Secondly, limited market access for cassava farmers is a significant challenge. Inadequate infrastructure, limited market information, and weak coordination between farmers and buyers result in difficulties in accessing good market opportunities. Thirdly, pest and disease attacks frequently occur in cassava plants, such as whiteflies, red mites, and stem rot. Insufficient knowledge and skills among farmers in controlling these pests and diseases lead to crop damage and decreased yields. Fourthly, the generally low fertility and non-ideal pH levels of Indonesian soils for cassava growth contribute to suboptimal plant growth and maximum yield production. Fifthly, natural disasters such as floods, droughts, and cassava plant diseases frequently occur in Indonesia. These natural disasters can cause crop damage and reduce yields. The complexity of these factors results in low cassava production in Indonesia and requires serious efforts from various stakeholders to improve it. These efforts include enhancing farmers' knowledge and skills, strengthening market access, developing superior varieties, improving soil fertility, and mitigating natural disasters.

The low cassava production in Indonesia affects not only farmers but also national food security and the country's economy. Cassava is a vital food source for the Indonesian population and serves as a raw material for various industries. The low cassava production can result in food shortages and increased prices of cassava-based products. Therefore, this issue poses a serious challenge for farmers, especially with the average yield being only around 20 tons per hectare, significantly below its actual potential. This problem encompasses inefficiencies in production management and a lack of optimal yields.

To address this issue, an innovative solution has been found through the application of Fuzzy Logic in cassava production management. By considering linguistic values and rules based on human knowledge, Fuzzy Logic helps optimize production decisions, enhance efficiency, and ultimately improve cassava production yields. This approach is expected to make a positive contribution to addressing cassava production challenges and improving the welfare of farmers because production planning becomes a crucial element that requires special attention to the number of required elements. Industries must have efficient capabilities in managing resources to achieve optimal production results and income (Nasution & Prakarsa, 2020).

Fuzzy logic is an approach to logic that considers and accommodates uncertainty, vagueness, and continuous membership levels. In fuzzy logic, a value can be partially true and partially false simultaneously, unlike classical logic, which only acknowledges true or false values in a crisp form (Setia STM Tunas Bangsa Bandar Lampung bsetia, 2019).

Fuzzy Logic is a concept that emerged due to aspects of real-life situations that often cannot be mathematically modeled and are inherently uncertain. This concept was first proposed by Prof. L. A. Zadeh in 1965 from the University of California. Fuzzy sets are an extension of crisp sets, where this set divides a group of individuals into two categories: members and non-members.

The fundamental difference between crisp sets and fuzzy sets lies in the membership values. In crisp sets, membership values have only two possibilities, 0 or 1, whereas in fuzzy sets, membership values range from 0 to 1. For instance, if x has a fuzzy membership value of $\mu A[x]=0$, then x is not a member of set A, and if x has a fuzzy membership value of $\mu A[x]=1$, then x is a full member of set A. The membership function is a curve that maps input data points to membership values ranging from 0 to 1. Several functions can be used to obtain membership values, such as linear representation, triangular curve, trapezoidal curve, and bell-shaped curve. The basic operators in fuzzy set operations defined by Zadeh include AND, OR, and NOT operators. The implication function is used to associate rules in fuzzy knowledge bases with fuzzy relations. Defuzzification methods, such as the Centroid Method, are used to convert fuzzy sets into crisp values that can be used as outputs. The membership function is a curve that maps input data points to their membership values ranging from 0 to 1. Several functions can be used, such as linear representation, triangular curve, trapezoidal curve, and bell-shaped curve (Kusumadewi, 2004).

Fuzzy Logic is one method used to analyze systems containing uncertainty. In this research, the Mamdani method, also commonly known as the Min-Max method, is employed. The system design to obtain output is conducted through the following steps: (a) Formation of fuzzy sets, (b) Application of implication functions, (c) Composition of rules, and (d) Defuzzification (Sitepu E, 2018).

The Fuzzy-Mamdani method, often referred to as the Min-Max method, was introduced by Ebrahim Mamdani in 1975. In this method, each rule in the form of an implication ("if-then") has antecedents in the form of conjunctions (AND) with minimum membership values (min), while their consequences have maximum combined values (max). This is because the rule sets are independent of each other (not interdependent) (Setiadji, 2009).

According to M. Munoz, E. Miranda, and PJ. Sanchez (2017) in their journal titled "A Fuzzy System for Estimating Premium Cost of Option Exchange Using Mamdani Inference: Derivatives Market of Mexico," fuzzy logic can be used to approach decision-making problems more flexibly than conventional mathematical approaches. They state that fuzzy logic enables problem-solving by considering the uncertainty and ambiguity often present in the context of human decisions. Fuzzy logic introduces the idea that in many cases, there isn't always a solution that is right or wrong, but a solution that considers intermediate conditions may be required to achieve satisfactory results. Thus, fuzzy set theory provides an adaptive approach to different contexts and conditions.

Fuzzy logic can be likened to a black box that connects the input space with the output space. This black box contains methods or techniques for processing input data to produce output in the form of useful information (Gelley, 2000).

Bojadziev G. and Bojadziev M. (2007) explain that fuzzy logic is an extension of logic that has many values, where the formation of fuzzy sets and fuzzy relations becomes a tool for forming systems with many logical values.

One of the widely used models in fuzzy logic is the Mamdani model. Mamdani Fuzzy Logic is an approach in fuzzy logic used for problem-solving by mapping inputs to output spaces using rules expressed linguistically. In Mamdani fuzzy logic, there are four main stages:

1. Formation of Fuzzy Sets (Fuzzification): This stage converts input values that have definite truth (crisp input) into fuzzy input forms. Input and output variables are expressed in fuzzy sets with membership functions reflecting uncertainty or truth levels.

2. Implication Function: At this stage, rules are established to connect input variables with output variables. The implication function is used to determine the extent of the contribution of a rule to the output value.
3. Rule Composition: This stage maps several rules that are satisfied regarding fuzzy values. If multiple rules are satisfied, the output value is taken as the largest value from the output value of a rule.
4. Defuzzification: This stage converts the fuzzy values obtained from rule composition into concrete or crisp values that can be used as the system's output. In the Mamdani method, one common defuzzification method used is the centroid method.

Fuzzy Logic Mamdani provides the system with the ability to handle uncertainty and complexity in decision-making by considering linguistic values and rules based on human knowledge (Kurniadi et al., n.d.). With the implementation of this technology, farmers can overcome inefficiencies in production management and improve both the quantity and quality of their harvests. Additionally, Fuzzy Logic Mamdani also helps reduce the risk of production errors. Thus, the use of Fuzzy Logic Mamdani is expected to positively contribute to increasing the productivity and welfare of cassava farmers in Indonesia.

Efficiency is a measure that compares the input used with the output produced. In the context of agriculture, efficiency has three aspects: technical efficiency, price efficiency, and economic efficiency. A farm is considered technically efficient if it can produce more output than other farms using the same inputs, or produce the same output using fewer inputs (Deras & Sinulingga, 2021).

Optimal profits are obtained from sales that match market demand. If the quantity of products produced is less than demand, the company will miss the opportunity to maximize profits. Conversely, if the quantity of products produced exceeds demand, the company will incur losses. Therefore, proper production planning is crucial to meet market demand effectively. Factors to consider in determining production quantity include demand and inventory from previous periods (Nasution & Prakarsa, 2020).

This research is expected to be a significant source of benefits for cassava producers overall. By applying the Mamdani Fuzzy method as a tool to optimize production decisions, it is hoped that cassava farmers can achieve higher levels of efficiency, improve product quality, and reduce production error risks. Overall, this study provides a clear and relevant overview of CASSAVA PRODUCTION REGULATION OPTIMIZED THROUGH FUZZY LOGIC TO IMPROVE EFFICIENCY AND PRODUCTION RESULTS. Understanding the challenges faced by cassava producers and recognizing the importance of appropriate analytical methods to address these challenges will help understand the value and relevance of this research in the overall context of cassava producers. The contribution of this research is expected to have a positive impact on developing best practices and improving efficiency for cassava farmers. Furthermore, this research is expected to make a significant contribution to the field of cassava farmer production management, enabling farmers to manage production more accurately.

METHODS

This research method involves several steps. Firstly, the collection of cassava production data is conducted at the location, which includes environmental conditions. This data involves information about production quantity, weather conditions, and other environmental factors that can affect the harvest. The method used for data collection employs the Mamdani Fuzzy Interface System method. The Fuzzy Interface System is a system that maps inputs to outputs using fuzzy logic. The Mamdani FIS method, also known as the Min-Max method, uses implication rules with minimum membership values for antecedents and maximum values for consequents.

In the next stage, fuzzy logic is applied to analyze and process the production data. Fuzzy logic is used to establish rules that model the relationship between environmental factors and production outcomes. By utilizing the concept of fuzzy membership, fuzzy logic can adjust decisions automatically based on the level of uncertainty and complexity in the environment.

The calculation application we use is MATLAB. MATLAB, an abbreviation for "matrix laboratory," was first introduced by the University of New Mexico and the University of Stanford in 1970. Initially, this software was used for numerical analysis, linear algebra, and matrix theory. However, MATLAB has now evolved into a more comprehensive tool with a wide range of additional toolboxes. MATLAB is extensible, meaning users can write new functions to be added to the library if the built-in functions available cannot accomplish the desired tasks.

In detail, here are the method steps that we conducted:

1. Pre-processing
   In the pre-processing stage, we collect the data and indicators that will be used in this study, such as input data 1 for temperature and the indicators related to that temperature.
2. Processing
   In this processing stage, we perform fuzzification, rule base formation, inference engine, and defuzzification.
3. Post-processing
   In this post-processing stage, we obtain the data that becomes the output of the conducted research (Mahardika & Sumantri, 2022).

Image 1. A photo of one of the team members with a cassava farmer

This photo was taken during data collection with a local cassava farmer as the informant, on February 18, 2024, at a cassava farm owned by the farmer in the Yasmin area, West Bogor.

Image 2. Cassava plantation owned by a farmer

The cassava plantation owned by the farmer covers an area of approximately 3 hectares and is surrounded by densely populated residential areas. Therefore, the cassava plantation is not very extensive, resulting in a relatively small harvest.

In determining cassava production using Mamdani fuzzy logic with the help of MATLAB. The following is the flowchart for the cassava production determination process.

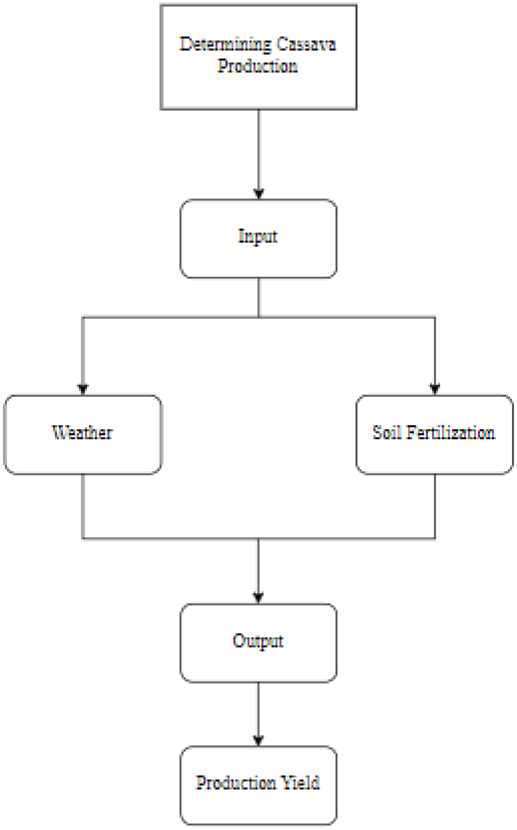

Figure 1. Cassava Production Determination Process Flowchart

Based on the above flowchart, determining the level of cassava production requires 2 inputs, namely weather factors and soil fertilization, where rainfall is measured by the intensity of rainfall and soil fertilization is determined by how often the soil is fertilized.

Table 1. Cassava Production Quantity

Cassava Production Quantity	**Low**	**Medium**	**High**
Low	Low	Medium	High
Medium	Medium	High	High
High	Medium	High	High

The test results for each plot of land obtained depend on both the rainfall and the condition of fertilization intensity. It can be seen that on average, to achieve high production yields, rainfall ranging from moderate to high is required, and this does not affect the condition of the land itself.

Table 2. Input Variable

Input	**Parameter**	**Parameter Number**
Weather	Low Medium High	[200 250 300 350] [340 375 425 460] [450 500 550 600]
Soil Fertilization	Low Medium High	[20 38 50 65] [60 92 120 150] [140 179 200 200]

Table 3. Output Variable

Output	Parameter	Parameter Number
Production Results	Low Medium High	[50 100 150] [120 175 220] [200 300 300]

The Membership Function in Determining Cassava Production

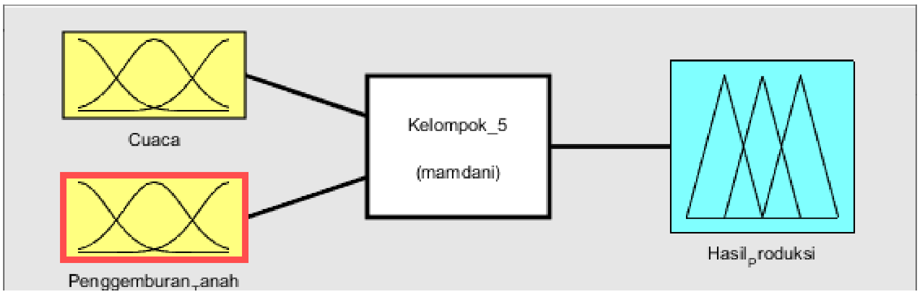

Figure 2. Creating Membership Functions in MATLAB

The graph shown is the result of data obtained from interviews conducted with cassava farmers. There are two input variables used: weather and soil fertilization. The output variable is the cassava production yield, and below is a more detailed explanation.

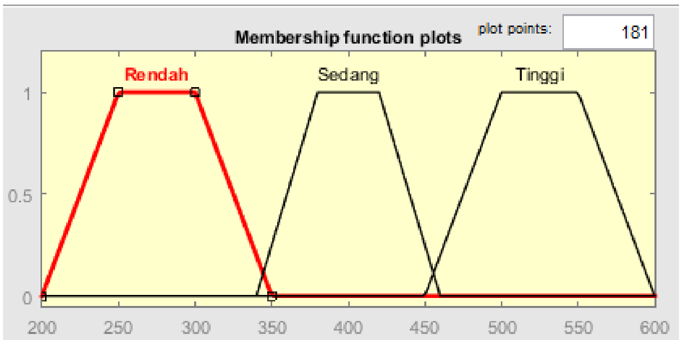

Figure 3. Membership Function with weather input in MATLAB

In the image above is the membership function of the weather input variable where the variable is created with a trapezoidal type and has a range from 200 to 600 with three parameters, namely Low, Medium, and High. It can be seen that the parameter value for Low is 200-350, the parameter value for Medium is 340-460, and the parameter value for High is 450-600.

Figure 4. Membership Function with soil fertilization input in MATLAB

In the image above, the membership function of the second input variable, Soil Fertilization, is shown. This variable employs a trapezoidal type with a range of values from 0 to 200 and consists of three parameters: Low, Medium, and High. For the Low parameter, the range is from 20 to 65. The Medium parameter has a range from 60 to 150. Meanwhile, the High parameter ranges from 140 to 200. This provides a visual representation of how far a value can be categorized as Low, Medium, or High in the context of this system.

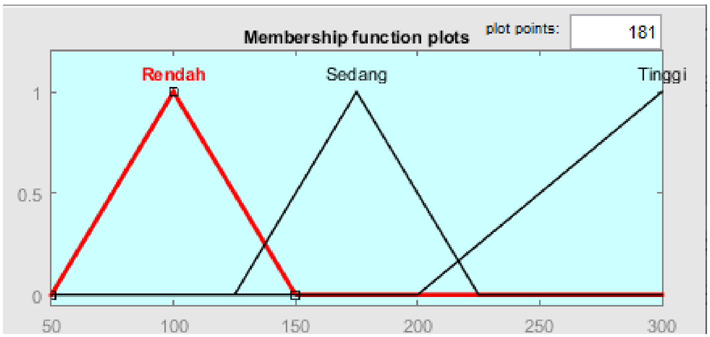

Figure 5. Membership Function with production yield output in MATLAB

In the picture above is the membership function of the output variable, namely the Production Yield. This variable is created with a Triangular type and has a range from 50-300 with 3 parameter values namely Low, Medium, and High. Where the value of the Low parameter is 50-150, the value of the Medium parameter is 125-225, and the value of the High parameter is 200-300.

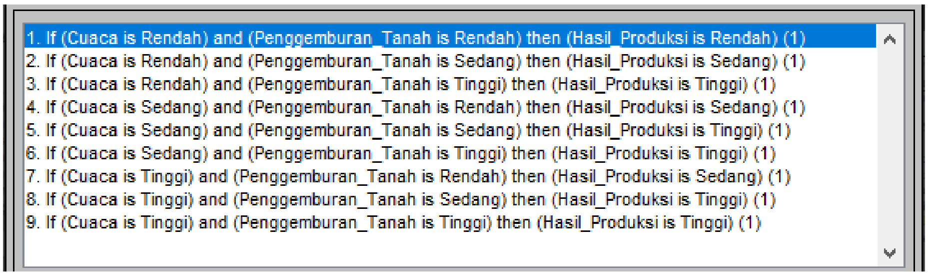

Figure 6. Fuzzy Mamdani logic rules in MATLAB

The input variables each have 3 parameters; therefore, the rules that can be created are 3x3 = 9 rules. The output variable also has 3 parameters according to the data we obtained.

Membership Function

The membership function of this input set is created based on interview data and adjusted with the graphs generated in the Matlab application, which will later be used to calculate the cassava production based on each parameter to determine the degree of membership value (µx). Here is the data of the membership function for the input variable:

Based on the description provided, let's define the membership functions for the input variables "Weather", "Soil Fertilization", and the output variable "Production Yield".

Input Variable “Weather”:

- Low: Trapezoidal (200-350)

$$\mu Low(x) = \begin{cases} 1 & if\ 200 \leq x \leq 250 \\ \frac{350-x}{100} & if\ 250 < x \leq 350 \\ 0 & if\ x > 350 \end{cases}$$

- Medium: Trapezoidal (340-460)

$$\mu Medium(x) = \begin{cases} 0 & if\ x \leq 340 \\ \frac{x-340}{60} & if\ 340 < x \leq 400 \\ 1 & if\ 400 < \ x \leq 460 \\ \frac{460-x}{40} & if\ 460 < x \leq 500 \\ 0 & if\ x > 500 \end{cases}$$

- High: Trapezoidal (450-600)

$$\mu High(x) = \begin{cases} 0 & if\ 200\ x \leq 450 \\ \frac{x-450}{150} & if\ 450 < x \leq 600 \\ 1 & if\ x > 600 \end{cases}$$

Input Variable "Soil Fertilization":

- Low: Trapezoidal (0-200)

$$\mu Low(x) = \begin{cases} 1 & if\ 0 \leq x\ \leq 20 \\ \frac{65-x}{45} & if\ 20 < x \leq 65 \\ 0 & if\ x > 65 \end{cases}$$

- Medium: Trapezoidal (60-150)

$$\mu Medium(x) = \begin{cases} 0 & if\ x \leq 60 \\ \frac{x-60}{90} & if\ 60 < x \leq 150 \\ 0 & if\ x > 150 \\ 0 & if\ x > 150 \end{cases}$$

- High: Trapezoidal (140-200)

$$\mu High(x) = \begin{cases} 0 & if\ x \leq 140 \\ \frac{x-140}{60} & if\ 140 < x \leq 200 \\ 1 & if\ x > 200 \end{cases}$$

Output Variable "Production Yield":

- Low: Triangular (50-150)

$$\mu Low(x) = \begin{cases} 1 & if\ 50 \leq x\ \leq 100 \\ \frac{150-x}{50} & if\ 100 < x \leq 150 \\ 0 & if\ x > 150 \end{cases}$$

- Medium: Trapezoidal (60-150)

$$\mu Medium(x) = \begin{cases} 0 & if\ x \leq 125 \\ \frac{x-125}{50} & if\ 125 < x \leq 170 \\ \frac{225-x}{50} & if\ 175 < x \leq 225 \\ 0 & if\ x > 225 \end{cases}$$

- High: Trapezoidal (140-200)

$$\mu High(x) = \begin{cases} 0 & if\ x \leq 200 \\ \frac{x-200}{100} & if\ 200 < x \leq 300 \\ 1 & if\ x > 300 \end{cases}$$

These membership functions reflect the characteristics of each input and output variable as described. The next step is to create rules that will serve as guidelines in the process leading to Defuzzification. These rules are created using parameters from two or more input variables.

Defuzzification

Defuzzification in the Mamdani rule-based system is done using the centroid method. In this method, a crisp solution is obtained by determining the center point of the fuzzy region. Generally formulated as: $\mu(x) = \frac{\int_a^b x\ \mu\ (x) dx}{\int_a^b x\ \mu\ (x) dx}$

In the defuzzification process, the first step is to determine the values of X1 and X2 from the previously calculated data. These values of X1 and X2 are derived from the output variable graph and based on the predefined rules. Here is the defuzzification process by determining the values of X1 and X2 from the previously calculated data:

Centroid = $\frac{\sum(Membership\ Value \text{xweight})}{\sum Membership\ Value}$

Centroid = $\frac{(0.17\text{x}150)+(0\text{x}175)+(0\text{x}200)+(0.36\text{x}150)+(0.78\text{x}175)+(0\text{x}200)+(0\text{x}150)+(0\text{x}175)+(0\text{x}200)}{0.17+0+0\pm0.36+0.78+0+0+0+0}$

Centroid = $\frac{25.5+0+0+54+136.5+0+0+0+0}{1.31}$

Centroid ≈ $\frac{216}{1.31} \approx 165.65$

Weather:

- $\mu Low(333) = \frac{350-333}{100} = 0{,}17$
- $\mu Medium(333) = \frac{333-340}{60} = 0$
- $\mu High(333) = \frac{333-450}{150} = 0$

Soil Fertilization:

- $\mu Low(131) = \frac{65-131}{45} = 0{,}36$
- $\mu Medium(131) = \frac{131-60}{90} = 0{,}78$
- $\mu High(131) = \frac{131-140}{60} = 0$

From all the obtained data, the final step is the Defuzzification process by dividing the total moment by the area. Below are the steps of Defuzzification:

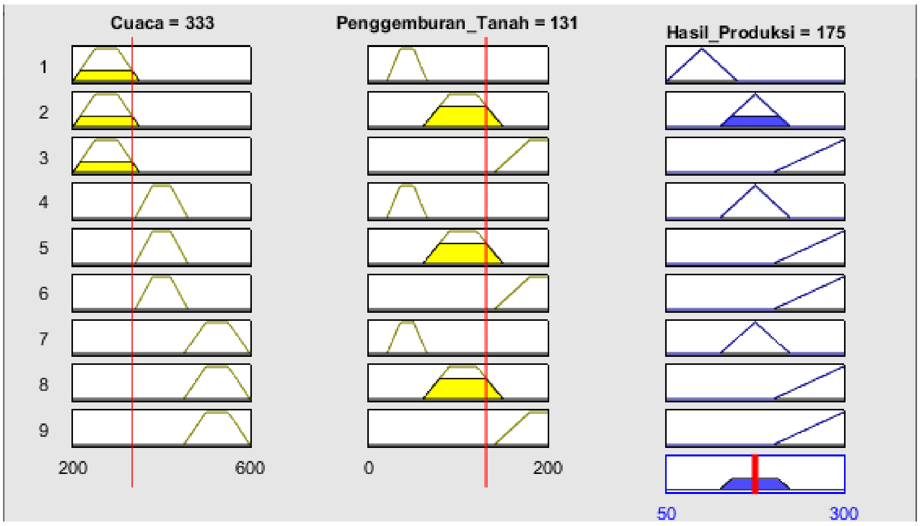

Figure 7. Defuzzification Result in MATLAB

From the process above, we obtained the final value of 175 with a margin of error of 9.35. This value of 175 represents the level of cassava production with low weather and medium soil fertilization. In this case, it can be proven that the calculations are by the rules that have been used, namely "If the Weather is Low and the Soil Fertilization is Medium, then the level of Cassava Production is Medium". To verify the accuracy of the calculation, we conducted a trial on the MATLAB application with the input Weather = 333 and Soil Fertilization = 131, and the result showed the value of 175, which is consistent with the calculation performed, with the output result in the MATLAB application.

CONCLUSION

The research results indicate that the use of fuzzy logic in cassava production management can significantly improve efficiency and production output. Optimizing cassava production through fuzzy logic enables adaptive adjustment to changes in environmental conditions, such as weather fluctuations and market demand changes.

The application of the Mamdani Fuzzy method in analysis and decision-making successfully addresses the uncertainty that often hinders cassava production. Fuzzy rules formed through fuzzy logic provide more accurate guidance in determining the optimal production quantity, avoiding excess or shortage of stock, and reducing production error risks.

Further discussion involves the implications of the research results for cassava producers. By adopting the Mamdani Fuzzy method, cassava farmers can enhance their production efficiency, improve product quality, and reduce overall production costs. Additionally, adaptive production management can help farmers cope with changing environmental challenges.

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