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APPLICATION OF SUGENO'S FUZZY INFERENCE SYSTEM (FIS) IN DETERMINING PALM OIL PRODUCTION

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ABSTRACT Palm oil is an important export commodity in Indonesia, and factors such as palm oil prices, production, and palm oil prices influence palm oil production. In this research, the fuzzy logic method is used to overcome uncertainty in predicting palm oil production. Various fuzzy methods, including Mamdani, Tsukamoto, and Sugeno, are used to model production based on certain factors. The type of research carried out in this research is a literature study and this research uses secondary data or data obtained by other parties. Secondary data taken is CPO price data, palm oil prices and palm oil production data. The prediction results for palm oil production using the Sugeno fuzzy method for several months are based on factors such as CPO prices and palm oil prices in the fuzzy system. The final results of MAPE provide information about the level of accuracy of the model in predicting palm oil production, which is 7.09%. FIS Sugeno connects input-output with fuzzy rules. The steps include variable selection, membership functions, rules, inference, defuzzification, evaluation, optimization, and implementation. The predicted MAPE is 7.09%, indicating the accuracy of the model in estimating palm oil production compared to the actual value.

Keywords: fuzzy sugeno, palm oil, MAPE.

ABSTRAK Produksi kelapa sawit yang merupakan komoditas ekspor penting di Indonesia, dipengaruhi oleh variabel seperti harga minyak, produksi, dan kelapa sawit. Dalam penelitian ini, metode logika fuzzy digunakan untuk mengatasi ketidakpastian dalam memprediksi produksi kelapa sawit. Berbagai metode fuzzy, termasuk Mamdani, Tsukamoto, dan Sugeno, digunakan untuk memodelkan produksi berdasarkan faktor-faktor tertentu. Metode Sugeno dipilih karena kemampuannya menghasilkan output yang presisi, sederhana, dan sesuai untuk model sistem kompleks seperti prediksi produksi kelapa sawit. Tujuan penelitian ini adalah untuk menentukan proses Fuzzy Inference System (FIS) Sugeno dalam menentukan prediksi produksi kelapa sawit serta keakuratan FIS dalam menentukan prediksi tersebut. Penelitian ini menggunakan data sekunder. Data sekunder yang diambil adalah data Harga CPO (Crude Palm Oil), Harga Kelapa Sawit, dan data Produksi kelapa Sawit. Hasil prediksi produksi kelapa sawit menggunakan metode fuzzy Sugeno selama beberapa bulan didasarkan pada faktor-faktor seperti harga CPO dan harga kelapa sawit dalam sistem fuzzy.

Metode Fuzzy Sugeno berkontribusi dalam menghasilkan model prediksi produksi kelapa sawit dengan tingkat akurasi tinggi, sebagaimana dibuktikan oleh nilai MAPE sebesar 7,09%.

Kata-kata kunci: fuzzy sugeno, MAPE, produk kelapa sawit

INTRODUCTION

Palm oil is an industrial and plantation crop that plays a strategic role in the Indonesian economy. This plant produces various high-value products such as fuel, cooking oil, and industrial oil (Kadim & Arliana, 2014). As one of the main export commodities, palm oil contributes significantly to the country's foreign exchange and financial and social growth. In addition, palm oil also supports community welfare through job creation, especially in rural areas during the production process (Nasution et al., 2022)

Oil palms are widely distributed across various islands in Indonesia, including Sumatra, Kalimantan, Java, Sulawesi, Papua, and several other islands (Apriani & Hayati, 2021). The palm oil industry uses oil palm fruit as a raw material to produce products such as cooking oil, margarine, soap, cosmetics and pharmaceuticals (Andriyani & Sitohang, 2018). With such a large role in the national economy, palm oil is one of the key sectors in supporting Indonesia's economic growth. However, behind its contribution, there are challenges in managing and predicting palm oil production effectively. One of the main problems is the rapid and inconsistent variability of production, especially in Indonesia. The population factor per hectare is one of the main causes, because planting density has a direct correlation with the level of productivity of oil palm plants. Suboptimal planting density often causes a decrease in production.

According to the theory of Agricultural Production Economics (Syahidin & Erma, 2021), Production inputs such as land, labor, capital, and management affect the output or total production of a farming business. In the industrial context, inputs in the form of raw materials affect the total goods produced. In other words, the wider the area of oil palm cultivation, the greater the potential for production of Crude Palm Oil (CPO) which is the main raw material for Fresh Fruit Bunches (FFB), the final product of oil palm cultivation (Alham & Anzitha, 2020). An effective approach is needed to accurately identify and predict palm oil production to address these challenges. By understanding the factors that influence productivity, it is hoped that the palm oil industry can continue to contribute optimally to the Indonesian economy.

The factors that impact palm oil production in this writing are palm oil prices, palm oil production and palm oil prices. These factors are closely related to uncertainty in predictions because of their dynamic, complex and mutually influencing nature. Palm oil prices, for example, can fluctuate due to changes in the global market, export policies or international demand. Likewise, the level of palm oil production is

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influenced by various factors such as weather conditions, land availability and management efficiency, all of which are uncertain.

This uncertainty poses a challenge in generating accurate predictions using conventional methods, since the relationships between variables are often non-linear or difficult to describe with classical mathematical models. In this context, fuzzy logic becomes a relevant approach, as it is able to handle uncertain, ambiguous, or incomplete data by representing relationships between variables through linguistic logic-based rules. With fuzzy logic, the uncertainty in these factors can be modeled more flexibly to generate more accurate and adaptive predictions to real conditions (Salendah et al., 2022). Fuzzy logic is used because it is easy to understand, flexible, can model very complete nonlinear functions and is resistant to incorrect data. It is also an alternative to many current decision-making systems. Ilham & Fajri (2020) suggested that a system model would be created that could estimate total production by applying fuzzy logic.

Mamdani, Tsukamoto, and Sugeno methods are some methods that can be applied to implement fuzzy logic in the production optimization process. Mamdani method is also known as the max-min method was created in 1975 by Ebrahim Mamdani. The formation of fuzzy sets, application of implication functions (rules), composition of rules, and assertion (deffuzy) are the four steps needed to obtain output. Tsukamoto method is an extension of monotone reasoning. In this method, each consequence of the If-Then form must be represented by a fuzzy set with a monotone membership function. Therefore, the inference results of each rule are given crisply. The final result is obtained using a weighted averag (Juliandri, 2020). The reasoning of the Sugeno Fuzzy method is similar to the Mamdani Fuzzy method (Max-Min), but produces output in the form of constants, not fuzzy sets (Maulidda et al., 2022).

This research is supported by the study of Kadim & Arliana (2014) which shows that the Fuzzy Sugeno method with inventory, sales (as input), and purchases (as output) variables can help companies determine the amount of drug purchases with a success rate of 88.88%.

In addition, a similar study was also conducted by Anisah et al., (2021) which showed that the Sugeno model fuzzy system had an MSE value for learning data of 1114.229, a MAPE value of 2.921%, and a MAPE value for test data of 2443.776, respectively. The MAPE value for test data is 2.719%. The research conducted V. M. Nasution & Prakarsa (2020) with research findings illustrates that the total order value of 11,800 tons was generated by entering the amount of expenditure of 8,813.80 tons and total inventory of 9,328.35 tons in December 2016. The findings from this previous research emphasize that the Fuzzy Sugeno method is able to provide accurate and applicable prediction results in various business situations.

This study examines the determination of palm oil production by applying the Sugeno Fuzzy Inference System (FIS) Method. The Sugeno method was chosen because of its ability to produce precise, simple output, and is suitable for complex

system models such as palm oil production prediction. This study uses a zero-order Sugeno fuzzy model resulting from the calculation stage that produces the smallest point. The crisp output value (Z) is found through defuzzification, namely by changing the input, the fuzzy set resulting from the composition of fuzzy rules, into numbers in the domain of the fuzzy set. For defuzzification, a weighted average is used. Furthermore, the actual value is compared with the accuracy measures MSE (Mean Square Error) and MAPE (Mean Absolute Percentage Error).

This study aims to determine the process of Sugeno's Fuzzy Inference System (FIS) to determine palm oil production predictions and to determine the accuracy of Sugeno's Fuzzy Inference System (FIS) to determine palm oil production predictions.

METHODS

This research was conducted at the Digital Library of Medan State University with the time required for this research was two months. The type of research conducted was a literature study. Literature studies are used to obtain a strong theoretical basis, understand previous research findings and support analysis in the context of the research being conducted. The data used are secondary data in the form of palm oil prices, palm oil prices, and palm oil production data taken from scientific journals and online databases.

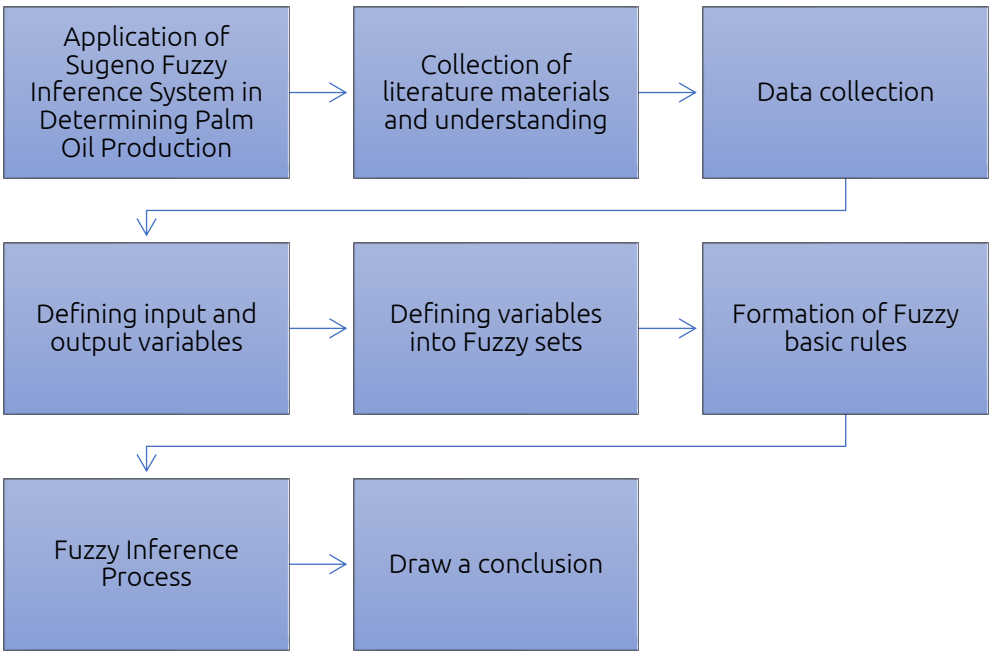

Figure 1. Research Procedure Scheme

The research procedure carried out began with the collection of data on palm oil prices, palm oil production and palm oil prices from January 2019 - December 2019. Data processing steps include defining input and output variables, changing variables into fuzzy sets, forming basic fuzzy rules, applying fuzzy logic with the Sugeno method, and drawing conclusions. The steps taken in completing the

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research on the application of the accuracy of the Sugeno Fuzzy Inference System (FIS) model in determining palm oil prices can be seen in figure 1.

FINDING AND DISCUSSION

Information regarding the variables in this study is presented in detail in table 1:

Table 1. Data on CPO Prices, Palm Oil Prices and Palm Oil Production 2019 Monthly Period

Month	CPO Price (x)	Palm Oil Prices (y)	Palm Oil Production (z)
Januari	6.098	1.257	2.453.928
Februari	6.445	1.325	2.252.071
Maret	6.546	1.335	2.329.803
April	6.417	1.313	2.407.421
Mei	6.284	1.252	2.592.234
Juni	6.110	1.235	2.471.317
Juli	6.000	1.199	2.651.640
Agustus	6.212	1.243	2.665.142
September	6.424	1.314	2.678.514
Oktober	6.401	1.290	2.643.474
November	7.180	1.440	2.482.644
Desember	7.896	1.630	2.431.815

From table 1 above, it is known that in January, the CPO price reached IDR6,098 per kg, while the price of palm oil and palm oil production were IDR1,257 per kg and 2,453,928 tons, respectively. In February, the CPO price rose to IDR6,445 per kg, followed by an increase in the price of palm oil and palm oil production to IDR1,325 per kg and 2,252,071 tons. March showed another increase with the CPO price reaching IDR6,546 per kg, the price of palm oil IDR1,335 per kg, and palm oil production of 2,329,803 tons.

In April, although the CPO price dropped slightly to IDR6,417 per kg, the price of palm oil and palm oil production remained high at IDR1,313 and 2,407,421 tons. In the following months, the data showed variations, with the highest value in December with the CPO price reaching IDR7,896 per kg, the palm oil price at IDR1,630 per kg, and palm oil production at 2,431,815 tons.

Throughout the year, CPO prices and palm oil prices showed quite significant fluctuations, which had an impact on palm oil production. At the beginning of the year, CPO prices started from IDR 6,098 per kg in January, increasing gradually to

reach a peak in December of IDR 7,896 per kg. Palm oil prices also followed an upward trend, from IDR 1,257 per kg in January to IDR 1,630 per kg in December. Palm oil production varied, with the highest volume in December at 2,431,815 tons, although throughout the year production fell in several months such as February (2,252,071 tons) and rose again in the following months. The correlation between price and production can be seen from the tendency for production to remain high or increase when CPO prices and palm oil prices rise, indicating that higher prices encourage increased production. The peak of production and price occurred in December, where CPO prices and palm oil prices reached their highest values throughout the year, followed by palm oil production which also peaked, indicating a positive relationship between price and palm oil production.

Further analysis of this data can provide insights into the dynamics of the CPO and palm oil markets during 2019. Variability in palm oil prices and production can be influenced by a number of factors including market demand, climate conditions, and industry policies. This is supported by previous research by Fevriera & Devi (2023) which shows that inflation, which can be influenced by economic policies and market conditions, has a significant negative effect on palm oil production, so that price and production variability is greatly influenced by economic factors and industrial policies. In line with this, Windirah & Novanda (2023) study using the ARCH/GARCH model revealed that CPO price volatility is influenced by external factors such as government policies regarding export taxes and price subsidies, as well as global market conditions, which have an impact on price uncertainty and palm oil production in Indonesia.

The formation of fuzzy sets using the Sugeno method based on the minimum and maximum values of each variable aims to identify optimal Palm Oil Production (z) in Indonesia, with the hope of providing economic benefits and increasing state revenues in the time span from January 2019 to December 2019. The Sugeno fuzzy method in this study is used to determine optimal palm oil production (z) in Indonesia based on the minimum and maximum values of each variable. The results are expected to provide recommendations that support increasing economic benefits and state revenues. The implications of this study include more targeted decision making in the management of palm oil production, so that it can support price stability, distribution efficiency, and sustainability of the palm oil plantation sector in Indonesia.

Furthermore, the universe of discussion on fuzzy set formation can be seen in table 2 as follows:

Table 2. Determination of the Universe of Discussion

Variable	Universe of Conversations	Information
CPO Price (x)	[6.000-7.896]	CPO Price per Month from January 2019 to December 2019

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Variable	Universe of Conversations	Information
Palm Oil Prices (y)	[1.199-1.630]	Palm Oil Prices per Month from January 2019 to December 2019
Palm Oil Production (z)	[2.252.071-2.678.514]	Palm Oil Production per Month from January 2019 to December 2019

Table 2 provides an explanation of the universe of discussion or range of values for each variable in this study. The observed variables involve CPO Price (x), Palm Oil Price (y), and Palm Oil Production (z) during the period from January 2019 to December 2019. First, for the CPO Price variable (x), the universe of discussion is set in the range between IDR6,000 per kg to IDR7,896 per kg. This range includes all CPO price values recorded during the time period studied. Thus, further analysis of CPO price variations can be interpreted in the context of this range. Furthermore, the Palm Oil Price variable (y) has a universe of discussion between IDR1,199 per kg to IDR1,630 per kg. This range includes all palm oil price data recorded during the study period. Therefore, further analysis of palm oil price fluctuations can be interpreted by considering this range. Finally, for Palm Oil Production (z), the universe of discussion is set in the range between 2,252,071 tons to 2,678,514 tons. This range includes all palm oil production data recorded during the months of 2019.

Then the fuzzy set is formed for each category of "Low", "Medium" and "High" for each type of input and output variable. The category is intended to determine the level of change of each variable each month and is shown in the following table:

Table 3. Fuzzy Sets

Variable Name	Fuzzy Set Name	Universe of Conversations	Domain (Unit)
CPO Price	Low	[6.000-7.896]	[6.000-6.632)
	Middle		[6.632-7.264)
	High		[7.264-7.896]
Palm Oil Prices	Low	[1.199-1.630]	[1.199-1.343)
	Middle		[1.343-1.486)
	High		[1.486-1.630]
Palm Oil Production	Low	[2.252.071-2.678.514]	[2.252.071-2.394.219)
	Middle		[2.394.219-2.536.366)
	High		[2.536.366-2.678.514]

From table 3 above, it is known that the CPO price range is from IDR 6,000 per kg to IDR 7,896 per kg with the low set covering prices between IDR 6,000 per kg to less

than IDR 6,632 per kg, medium between IDR 6,632 per kg to less than 7264, and high between IDR 7,264 per kg to 7,896 per kg. Second, the price of palm oil in the categories: low, medium, and high. The price range of palm oil is from IDR 1,199 per kg to IDR 1,630 per kg with the low set covering prices between IDR 1,199 per kg to less than IDR 1,343 per kg, medium between IDR 1,343 per kg to less than IDR 1,486 per kg, and high between IDR 1,486 per kg to IDR 1,630 per kg. Third, the amount of palm oil production, which also has three fuzzy sets: low, medium, and high. The low category includes production amounts between 2,252,071 tons to less than 2,394,219 tons, medium between 2,394,219 tons to less than 2,536,366 tons, and high between 2,536,366 tons to 2,678,514 tons. Fuzzy logic configuration is used to describe these three variables in a specific analysis context. Fuzzy logic configuration is used to model the three variables in the form of fuzzy sets, which allow the representation of numeric values within a certain range as a degree of membership. This process helps to overcome uncertainty and provides more flexible results in the analysis based on the specified rules.

The membership function of the CPO Price, Palm Oil Production and Palm Oil Price variables includes a linear curve shape down for the low set and a linear curve shape up for the high set. While the triangular curve is for the medium set. The membership function curve with a linear shape down for the low set, linear up for the high set, and triangular for the medium set is used in fuzzy analysis to classify the values of the CPO Price, Palm Oil Production and Palm Oil Price variables into three categories: low, medium, and high. With this approach, the analysis can capture uncertainty and ambiguity in the data, thus enabling more accurate and context-based decision making. The respective curves for the CPO Price, Palm Oil Production and Palm Oil Price variables that show the categories of each fuzzy set are shown as follows:

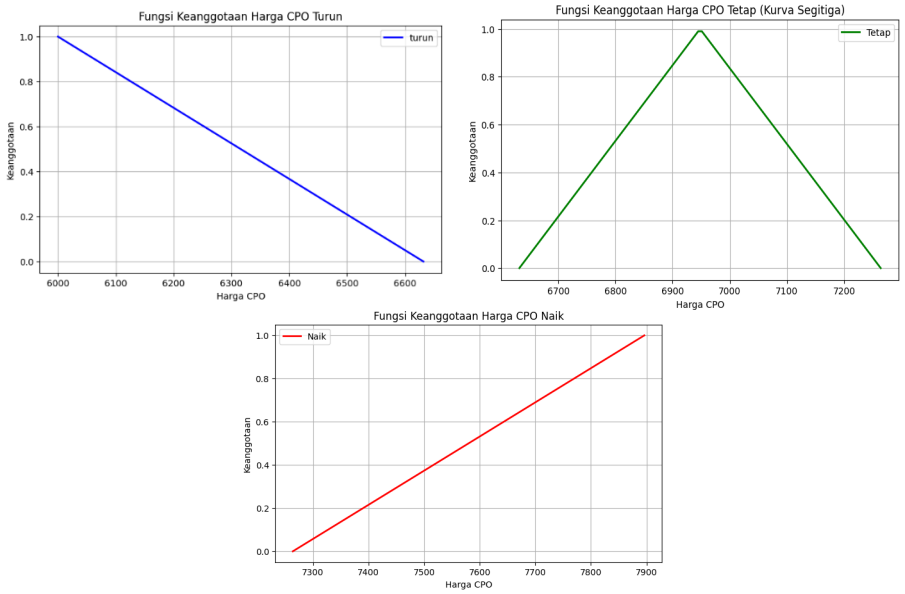

Figure 2. CPO Price Membership Function Graph

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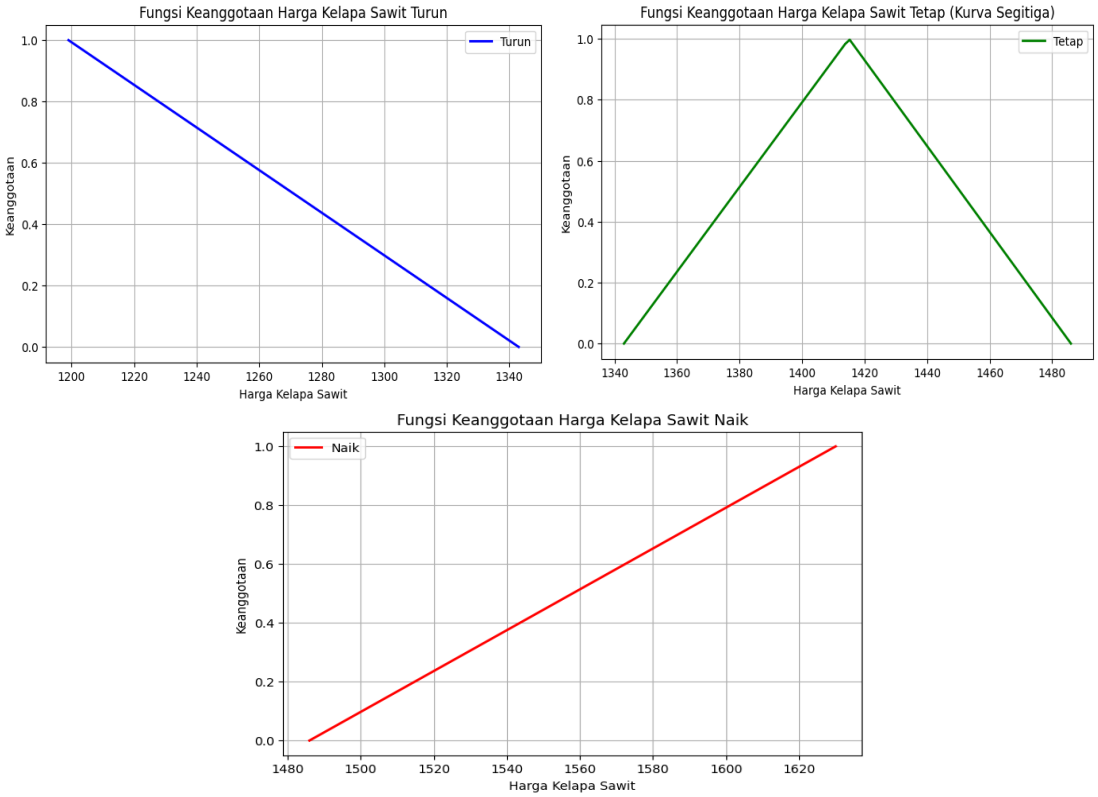

Figure 3. Palm Oil Price Membership Function Graph

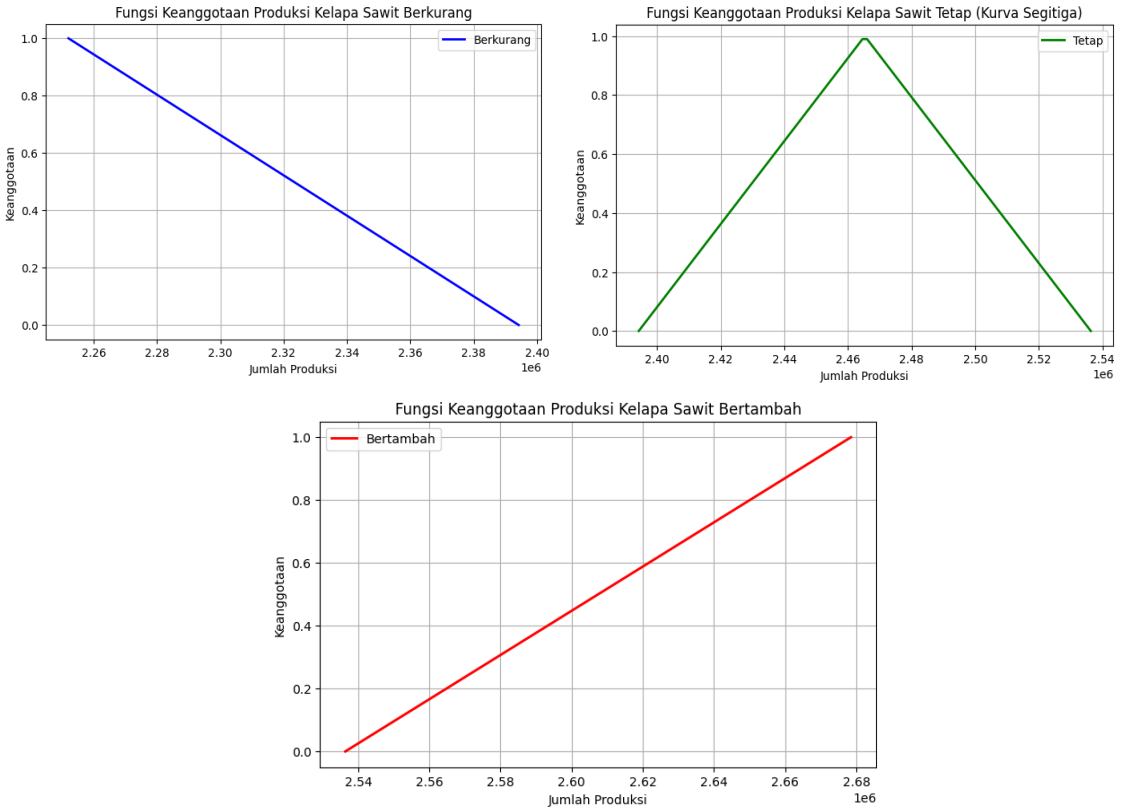

Figure 4. Palm Oil Production Membership Function Graph

In the context of palm oil production prediction using Fuzzy Sugeno, after the system performs inference based on fuzzy rules and the given input (such as CPO price and palm oil price), the output produced is in fuzzy form which refers to the representation of the results which are not only in the form of definite or binary values, but also include degrees of membership indicating the extent to which an element belongs to a particular category. To make palm oil production predictions that can be used in practical applications, a defuzzification process is required.

The defuzzification process is an important step that transforms fuzzy results into real values that represent the prediction of palm oil production. In other words, defuzzification takes fuzzy values that may have membership levels and returns a single value that describes a more concrete prediction. The calculation results for the prediction in 2020 are listed in table 4 as follows:

Table 4. Fuzzy Sugeno Prediction Results

Month	CPO Price (x) (per kg)	Palm Oil Prices (y) (per kg)	Palm Oil Production (z) (per ton)	Palm Oil Production Forecast (per ton)
Januari	6098	1257	2.453.928	2.323.145,00000076
Februari	6500	1325	2.300.000	2.323.144,99999978
Maret	6546	1335	2.329.803	2.323.144,99999655
April	6417	1313	2.407.421	2.323.144,99999976
Mei	6284	1252	2.592.234	2.323.145,00000058
Juni	6110	1235	2.471.317	2.323.145,00000001
Juli	6200	1199	2.651.640	2.323.144,99999639
Agustus	6212	1243	2.665.142	2.323.145,00000308
September	6424	1314	2.678.514	2.323.144,99999553
Oktober	6401	1290	2.643.474	2.323.145,00000168
November	7180	1440	2.482.644	2.465.292,43693528
Desember	7896	1630	2.431.815	2.607.439,99889068

Through table 4 above, there is an upward trend in the prediction of palm oil production. In the early phase of the observation period from January to October, there was a relatively stable fluctuation in the production prediction, with the predicted value ranging around 2323145. Although fluctuations occurred, there was no significant change in the prediction trend during the period.

However, there was a drastic change in November, where there was a significant spike in the predicted value, reaching around 2465292. This spike reflects the potential for external factors or other variables that may affect the prediction of palm oil production in that month. Although there was a slight decrease in

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December, the predicted value remained high, at around 2607440, becoming the highest value throughout the observation period.

The Model Evaluation Process using the Mean Absolute Percentage Error (MAPE) Method is an important step in assessing the extent to which the model performs in predicting palm oil production. MAPE is one of the evaluation metrics that allows us to understand the relative error rate between the value predicted by the model and the actual value in percentage form. The smaller the MAPE value, the better the model's performance in predicting palm oil production. A small MAPE (Mean Absolute Percentage Error) value indicates that the difference between the predicted value and the actual value is relatively small, which means that the model has high accuracy in predicting data. Thus, the model's performance is considered good because it is able to provide estimates that are closer to reality, thereby increasing confidence in data-based decision making. The MAPE value calculation process is carried out as follows:

$$MAPE = \frac{1}{12}\text{x}\sum_{i=1}^{12}\left|\frac{palm\ oil\ production\ prediction - palm\ oil\ production}{palm\ oil\ production}\right|\text{x}100\%$$

$$MAPE = \frac{1}{12}\text{x}\left(\left|\frac{2313145{,}00000076 - 2453928}{2453928}\right| + \left|\frac{2323144{,}99999978 - 2300000}{2300000}\right| + \cdots + \left|\frac{2607439{,}99889068 - 2431815}{2431815}\right|\right)\text{x}100\%$$

$$MAPE = 7{,}09\%$$

In this evaluation step, each palm oil production prediction generated by the model is compared with the actual palm oil production in the same period. This comparison produces a relative percentage error value, which is then averaged across the entire data. The final result of MAPE provides information about the level of error in forecasting palm oil production of 7.09%, meaning that, on average, the model is approximately 7.09% wrong in predicting palm oil production compared to the actual data.

According to Gusmira et al., (2022), MAPE values are processed into 4 categories in table 5, namely as follows:

Table 4. MAPE Value Categories

Percentage	Category
< 10 %	Very good
10 % - 20 %	Good
20 % - 50 %	Reasonable
> 50 %	Not accurate

The smaller the MAPE value, the smaller the error in the prediction results, conversely, the larger the MAPE value, the greater the error in the prediction results. The MAPE value of 7.09% indicates that the prediction model has an average error rate of around 7%, which is quite good for practical applications in medium to long-term production planning. With a MAPE below 10%, this model can be considered reliable to assist decision making because the prediction error is relatively small and can provide a fairly accurate picture of production or demand trends. However, for very critical or very long-term decisions, periodic evaluation and adjustment of the model is still needed to remain responsive to changes in market and production conditions. In the context of the palm oil business, factors such as market fluctuations and seasonality can affect the error rate in predicting palm oil production. Therefore, the results of the MAPE evaluation should be used together with a deep understanding of these factors to make better business decisions.

This is supported by the research of Yanto et al., (2019) which discusses the development of a fuzzy inference system with the TSK (Takagi Sugeno Kang) method to predict oil palm harvests in various seasons. This study shows that the FIS Sugeno method is able to provide accurate oil palm harvest predictions based on fuzzy modeled input variables.

CONCLUSIONS AND RECOMMENDATIONS

From the research conducted, it was concluded that (1) Sugeno type Fuzzy Inference System (FIS) is used to connect input with output based on fuzzy rules. The general steps in forming Sugeno FIS include selecting input and output variables, forming membership functions for these variables, determining fuzzy rules that connect input with output, fuzzy inference to produce fuzzy output, defuzzification to change output into crisp values, model evaluation and validation, optimization if necessary, and finally implementation of the model in real situations. Sugeno FIS can be used in various applications, including palm oil production prediction or in other decision-making contexts, and (2) Based on the results of Sugeno FIS prediction, the final MAPE provides insight into the model's error rate in predicting palm oil production of 7.09%. This indicates that the model has a very good accuracy rate of 7.09% in estimating palm oil production compared to its actual value.

Further research is suggested to develop Fuzzy Inference System (FIS) models other than the Sugeno type, such as the Mamdani FIS. Comparison between different types of FIS can provide a deeper understanding of the most suitable model for predicting palm oil production. In addition, model optimization and the use of additional relevant data, such as weather data and economic factors, can improve prediction accuracy by applying the model to a larger data scale.

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