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Forecasting Rice Paddy Production in Aceh Using ARIMA and Exponential Smoothing Models

Nurviana[1,*], Amelia[1], RiezkyPurnama Sari[1], UlyaNabilla[1], Taufan Talib[2]
[1]Mathematics Department, Universitas Samudra, Indonesia
[2]Mathematics Department, Universitas Pattimura, Indonesia

*Corresponding Author
Email: nurviana@unsam.ac.id*,
ameliamat@unsam.ac.id, riezkypurnamasari@unsam.ac.id,
ulya.nabilla@unsam.ac.id, taufan.talib@fkip.unpatti.ac.id

ABSTRACT

Indonesia targets Aceh to be one of the rice paddy production centers and be able to carry out self-sufficient production in rice paddy and become a national granary. However, in reality, Aceh's rice paddy production in its province is not consistent from year to year. This province has not been able to meet the food needs of rice paddy independently, so that it supplies rice paddy from other regions due to the difficulty of detecting the presence of a surplus of rice paddy.The purpose of this research is to forecast the yield ofrice paddy production in Aceh for the future. The mathematical model that can be used is a time series model namely Autoregressive Integrated Moving Average (ARIMA) and Exponential Smoothing. The forecasting results of rice paddy production in the next 5 years using the ARIMA (3,1,1) model are 2453401; 2154784; 2111594; 1615171; and 2062436. While the estimation results using the Winter Exponential Smoothing model are 1625925; 1645196; 1687667; 1605530; and 1555213. ARIMA model (3,1,1) produces an MSE/MAD value of $3{,}34041 \times 10^{10}$, while the Winter Exponential Smoothing model produces an MSE/MAD value of $3{,}08616 \times 10^{10}$. Therefore, it can be concluded that the Winter Exponential Smoothing model.By obtaining this resultsanalysis, the Aceh government can make the right policies in planning for the provision of rice paddy food in the future.

Keywords: ARIMA; Forecasting; Exponential Smoothing; Rice paddy

INTRODUCTION

Aceh is one of the provinces in Indonesia which has large agricultural land. The majority of the population in Aceh rely their life on the agricultural sector for their livelihood. According to the Central Bureau of Statistics, the highest economic source of Aceh is in the agricultural sector, where agriculture has a good contribution to the economy and fulfills the basic needs of the society. The agriculture of Aceh excels in various commodities such as rice paddy, corn, soybeans, and chilies. The rice paddy plants are stapled food crop commodities whose needs continue to increase from year to year following population growth.

Rice paddy cultivation is the main activity and main source of income for more than 100 million households in developing countries in Asia, Africa, and Latin America. In Asia-Pacific more than 90 percent of the world's rice paddy has been produced and consumed[1]. The rice paddy plant is an ancient agricultural crop that until now is considered a staple crop in most tropical countries, especially in Asia and Africa. Rice

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paddy is the most important food crop in Aceh because almost all people use rice paddy as a staple food and rice paddy is also a strategic food commodity that has a considerable influence on economic stability, especially inflation, social and political stability. Indonesia targets Aceh as one of the centers of rice paddy production and can carry out self-sufficient production in rice paddy and become a national granary [2]. Aceh has many genotypes or local rice paddy varieties. According to [3]there are 50 Aceh rice paddy genotypes that have been collected through exploration activities, but only a few local rice varieties are often planted.The varieties are Ramos, Dewi, Sigupai, Tinggong, and Siputeh.

Based on BPS [4], local rice paddy production of Aceh is not consistent from year to year or in other words, it increases and decreases every year. In 2020, the rice paddy plants production reached 1.75 million tons, an increase from the previous year of 1.71 million tons. If it is converted to rice paddy, in 2020 rice paddy production in Aceh will reach 1 million tons. This increase was due to an increase in the harvested area of rice paddy plants from 310.01 thousand hectares to 320.75 thousand hectares [4]. Therefore, the province of Aceh should have been able to meet the food needs of rice paddy independently. However, Aceh still supplies rice paddy from other regions due to the difficulty of detecting the presence of a surplus of rice paddy.

A mathematical model is needed to make plans related to food commodities, especially rice paddy. One of the mathematical models that can be used is the time series model. This model is used to estimate production results in the future period based on previous data. The time series model that will be used in this research is Autoregressive Integrated Moving Average (ARIMA) and Exponential Smoothing.

Previous research related to the study of rice paddy production has been carried out by [5]which discussed the forecast of rice paddy production in Gorontalo province using the double moving average method.The forecasting results for the next 5 years were obtained, in 2019 of 326318.5 tons, in 2020 of 32094.5 tons, and so on until 2023 of 304826.5 tons. Other research [6]using double exponential smoothing model to assess the estimated production value for the next year. The application of this model obtained predictions of rice paddy harvests in the Kudus Regency in 2019 of 163,435.90 tons. Other rice paddy production research [7]using the fuzzy time series model for forecasting the amount of rice paddy production in southeast Sulawesi, the results of forecasting rice paddy production in 2015 were 657768.25191 tons.

Based on the explanation above, researchers are interested in analyzing the rice paddy production results using the ARIMA and Exponential Smoothing models. The purpose of this study is to predict the local rice paddy production of Aceh result in the future period and to see which of the two models is the best in estimating Aceh's local rice paddy production. Therefore, hopes that the government can make more precise planning in the provision of rice paddy food and can make Aceh a national rice paddy production center.

METHODS

ARIMA Process

ARIMA is a time series model that can predict data for a certain period of time based on past data [8]. This model has very good accuracy when used for short-term forecasting. Meanwhile, for long-term forecasting, the accuracy of the forecast is not good and usually, it will tend to be flat (level or constant) for a fairly long period.

The ARIMA process developed by Box and Jenkins in 1976 was a model that does not assume certain patterns in the historical data that was forecasted and was a model that completely ignores the independent variables in making forecasts that were used in model formation[9]. The ARIMA process is a combined model between autoregressive (AR) and Moving average (MA). This model can represent stationary and non-stationary time series [10] - [11]. The general form of ARIMA model (*p,d,q*) is defined as[12]:

$$Y_t - Y_{t-d} = \gamma_0 + \sum_{i=1}^{p} \alpha_i (Y_{t-i} - Y_{t-i-d}) + \sum_{i=1}^{q} \beta_i \varepsilon_{t-i} + e_t \qquad (1)$$

In practice, the data is commonly non-stationary so that modifications need to be made, by using differencing, to produce stationary data.

Exponential Smoothing model

Exponential smoothing is an analytical time series model that is quite good and convenient in low ease of operation. The exponential smoothing model continuously makes improvements related to forecasting by taking the smoothing average of past values from a time series data by decreasing exponentially[13].

In general, the exponential smoothing model is divided into 3 models, namely single, double, and triple exponential smoothing (Holt-Winter's Model). This research concentrates on triple exponential smoothing. This model is used when the data pattern shows very large differences, trends, and seasonal behavior. To deal with seasonality, a third equation parameter has been developed called the "Holt-Winters" model after the name of the inventor.

The Holt-Winters method is based on three equations, namely stationary, trend, and seasonal elements[14]. The basic equation for the Holt-Winters method is as follows: [15]

Overall smoothing: $S_t = \alpha \frac{X_t}{I_{t-L}} + (1-\alpha)(S_{t-1} + b_{t-1})$

Trend smoothing: $b_t = \gamma(S_t - S_{t-1}) + (1-\gamma)b_{t-1}$

Seasonal smoothing: $I_t = \beta \frac{X_t}{S_t} + (1-\beta)I_{t-L}$

Forecast: $F_{t+m} = (S_t + b_t\, m) I_{t-L+m}$

RESULTS AND DISCUSSION

Analysis of the data on the data on the amount of rice paddy production using the ARIMA Box-Jenkins method and the Exponential Smoothing method. The data processed is data on rice paddy production in Aceh from 1993 to 2020 and analyzed with usingMinitab 19.

Data Characteristics Total Rice Paddy Production

Result data plot rice paddy production from 1993 to 2020.

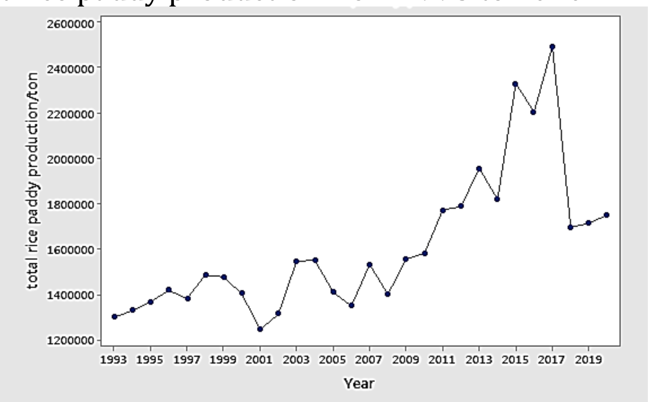

Figure 1. Time Series Plot of Total Rice Paddy Production in Aceh from 1993 to 2020

Descriptive statistics show the least quantity of rice paddy production in 2001 was 1,246,614 tons. Meanwhile, the highest number of productions occurred in 2017, which was 2.49613 tons and the average total rice paddy production from 1993 to 2020 is around 1.61315 tons. Based on Figure 1, the amount of rice paddy production tends to go up and down. The fluctuation of the data on the amount of rice paddy production is not at a constant average value so that there is an indication that the data is not stationary.

Forecasting Rice Paddy Production Using the ARIMA Model

a. Model Identification

The initial step in identifying the data is to know whether the data is stationary in the mean and variance. Identification has been done by determining: the time series plot, ACF plot, PACF plot, and Box-Cox transformation. The identification process starts from determining whether the rice paddy production data is stationary to the variance or not.

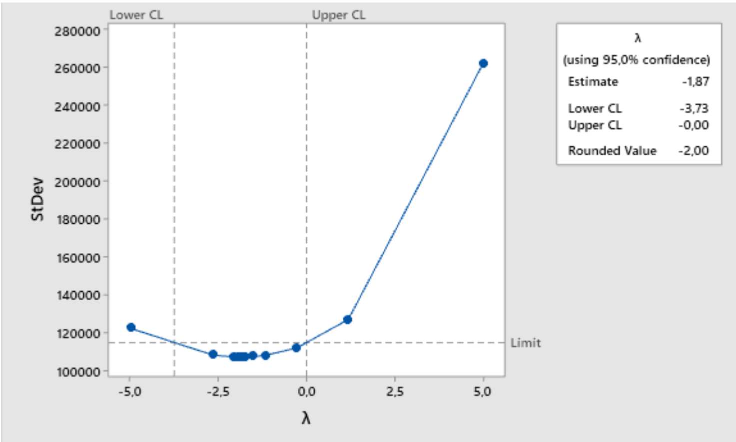

Figure 2. Box-Cox Plot of Total Rice Paddy Production

Based on Figure 2, the rice paddy production data is not stationary to the variance because the rounded value is less than 1, where the rounded value is said to be good if the value is 1.

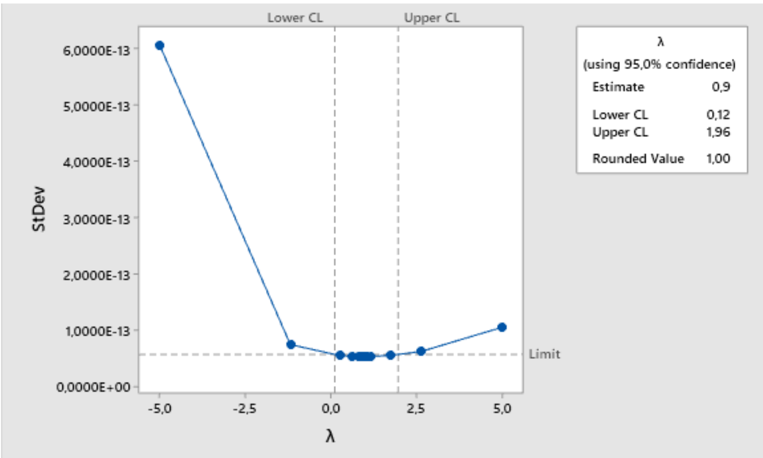

Figure 3. Box-Cox of Total Rice Paddy Production After Transformation

Based on Figure 3, a rounded value of 1.00 is obtained so that the data can be said to have been stationary in variance. Furthermore, the differencing stage is carried out so that the data is stationary to the mean. Stationary data to the mean can be seen visually through the ACF plot. The following is an ACF plot of total rice paddy production.

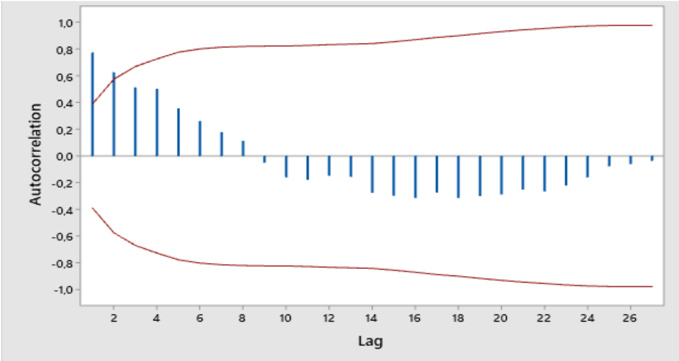

Figure 4. ACF Plot of Total Rice Paddy Production before differencing

Figure 4 shows that the quantity of rice paddy production is not stationary in the mean, because the lags in the ACF plot are still decreasing slowly. Therefore, it is necessary to do differencing. Here is the time series plot after differencing.

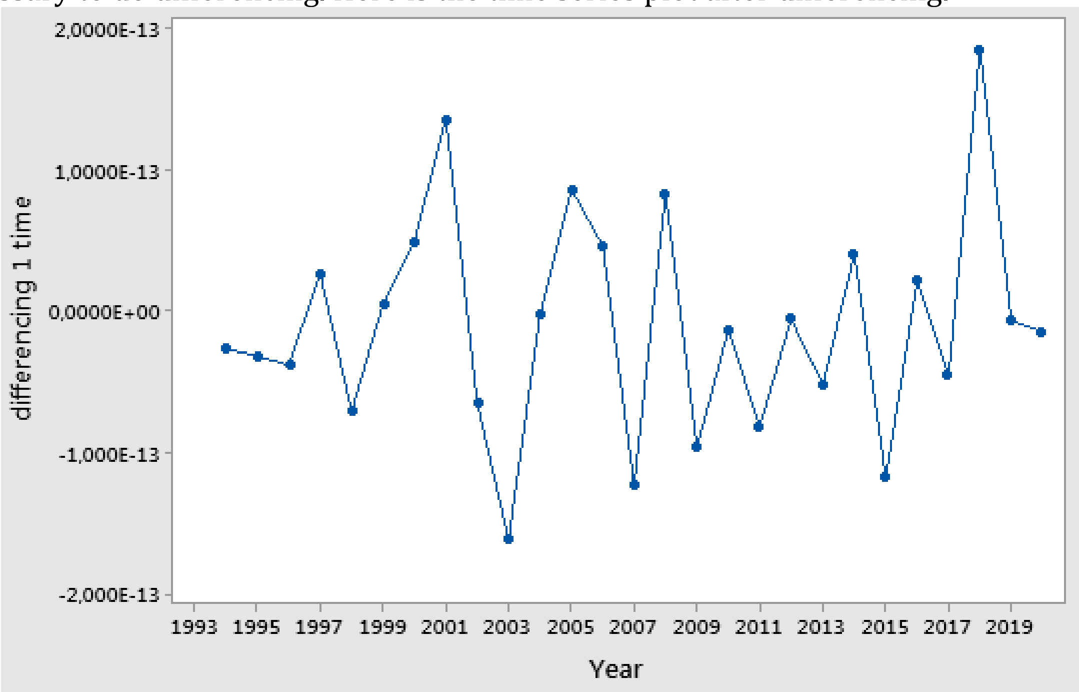

Figure 5. Time Series Plot of Rice Paddy Production After Differencing

Figure 5 shows that the pattern of the amount of rice paddy production is stationary in the mean after the differencing process is carried out once. The next step is to identify the model to get the ARIMA conjecture model. The identification of the ARIMA model has been known based on the ACF and PACF plots. The following is a plot of ACF and PACF for the amount of rice paddy production after the differencing process at lag 1.

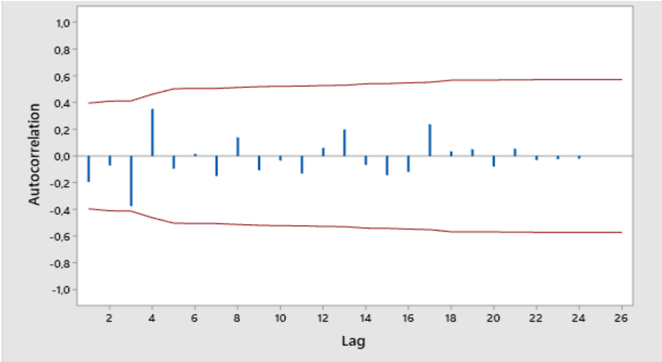

Figure 6. ACF Plot of Total Rice paddy Production Data After Differencing

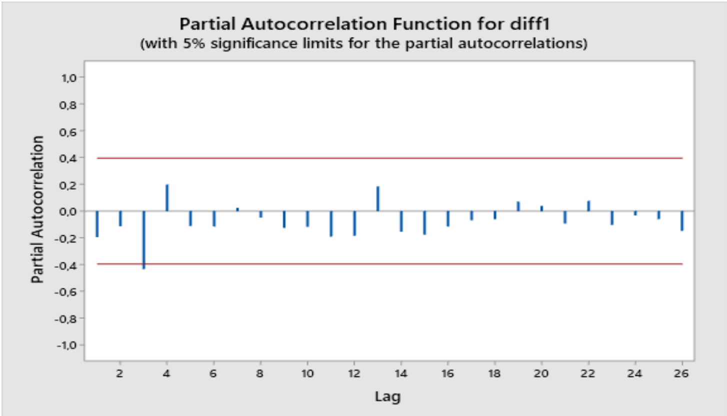

Figure 7. PACF Plot of Total Rice paddy Production Data After Differencing

Based on Figure 6 and 7, it is showing that there are no lags that come out or all lags are in a significant line in The ACF Plot, while the PACF plot is cut off at the 3rd lag. So it can be concluded that the suggested ARIMA (p,d,q) models for rice paddy production were (1,1,0), ARIMA (1,1,1), ARIMA (3,1,0) and ARIMA (3,1,1)

b. Estimation of parameters and Diagnostic Tests of Residual

The next step is the estimation of the model parameters for the tentative models that have been selected. The best model was selected based on the minimum values of Means Square Error (MSE).

Table 2. Suggested ARIMA (p,d,q) Models For Rice Paddy Production

Suspected Model	Estimates of Parameters			Mean Square Error Value
	Type	Coef	SE Coef	
(1,1,0)	ϕ_1	-0,354	0,183	4,32646E+10
(1,1,1)	ϕ_1	-1,028	0,276	3,95604E+10
	θ_1	-0,853	0,465	
(3,1,0)	ϕ_1	-0,171	0,179	3,36785E+10
	ϕ_2	-0,091	0,189	
	ϕ_3	-0,800	0,268	
(3,1,1)	ϕ_1	-0,396	0,339	3,34041E+10
	ϕ_2	-0,187	0,231	
	ϕ_3	-0,812	0,290	
	θ_1	-0,351	0,411	

Based on Table 2, the best selected ARIMA model for rice paddy production is ARIMA (3,1,1) with MSE =3,34041E+10. So, it can be analyzed in the next step, namely by testing the assumption of residual White Noise and normal distribution.

Testing the assumption of the residual White Noise is carried out using The Box-Ljung test statistic with the following hypothesis formulation:

H_0 : Residual White Noise

H_1 : Residual is not White Noise

If the significance level is set at 5%, then the rejection area is rejected H_0if $Q < x^2_{\alpha,df-K-p-q}$ or P-value> α.

Table 3. Results of The Box-Ljung Statistic for residuals of ARIMA (3,1,1)

Model	Lag	Q	DF	P-Value
(3,1,1)	12	3,51	8	0.898
	24	9.41	20	0.978
	36	*	*	*
	48	*	*	*

Based on Table 3, The Model of ARIMA (3,1,1) since p-value is greater than the level of significance we do not reject the null hypothesis. Indicated that the residuals for the model was white noise at the 5% level of significance.

Testing the assumption of normal distribution of residuals is carried out using the Kolmogorov Smirnov test. The following are the results of testing the normal distribution of the residual assumption.

Hypothesis:

H_0 : Residual-normally distributed

H_1 : Residual-not normally distributed

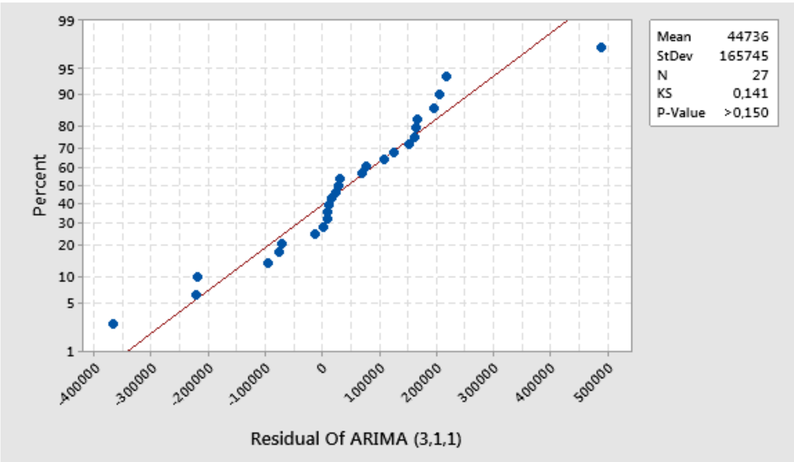

Figure 8. Probability Plot of Residual Of ARIMA (3,1,1)

Base on figure, The results of the residual of ARIMA (3,1,1) was 0,141 with an observed significance level of 0.05 indicating that residual for the model was normally distributed at the 5 % level of significance. Hence, the diagnostic test that ARIMA (3,1,1) model was appropriate for rice paddy production.

Table 6. Rice Paddy Production Forecasting Results using model ARIMA (3,1,1)

Year	Rice paddy Production Forecasting Results
2021	2453401
2022	2154784

Year	Rice paddy Production Forecasting Results
2023	2111594
2024	1615171
2025	2062436

Estimation Using Exponential Smoothing Model

The plot of rice paddy data shows that rice paddy production fluctuates every year. The graph also shows that start from 1993s, rice paddy production continued to experience a very significant increase until 2013. However, in 2018 rice paddy production decreased very rapidly, which is equal to 1,697,756 tons.

The existence of a trend element in rice paddy production (tons) can be seen from the results of the ACF (Autocorrelation Function) as it shown below.

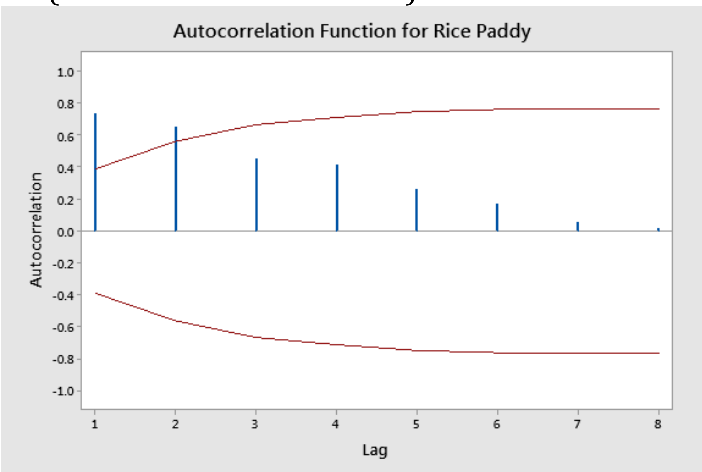

Figure 9. ACF Plot of Rice Paddy production

Based on the picture above, it can conclude that the data has an element of trend because the lag movement is slowly decreasing towards 0. The trend element can also spot from the results of trend analysis in the image below:

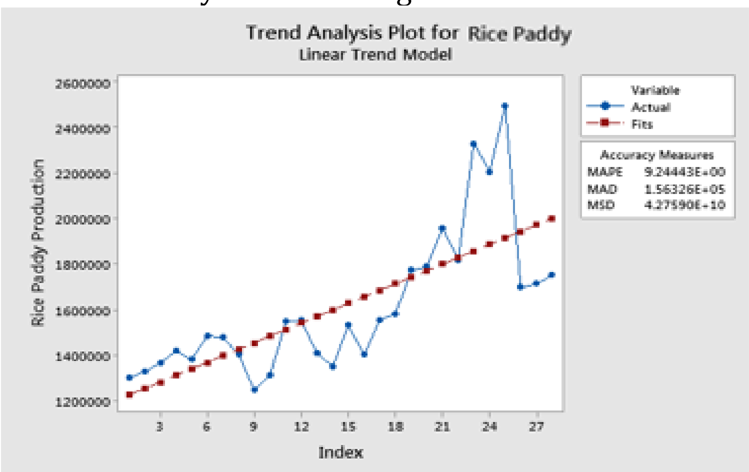

Figure 10. Trend Analysis Plot of Rice Paddy Production Trend Analysis Plot

In the figure 10, it is obvious that the data has an element of trend. It can be shown from the fits line that has increased linearly. When the fits line increases or decreases linearly, then the data have an element of trend.

The presence of seasonal elements in rice paddy production (tons) can spot from the PACF (Partial Autocorrelation Function) plot shown in the figure 12.

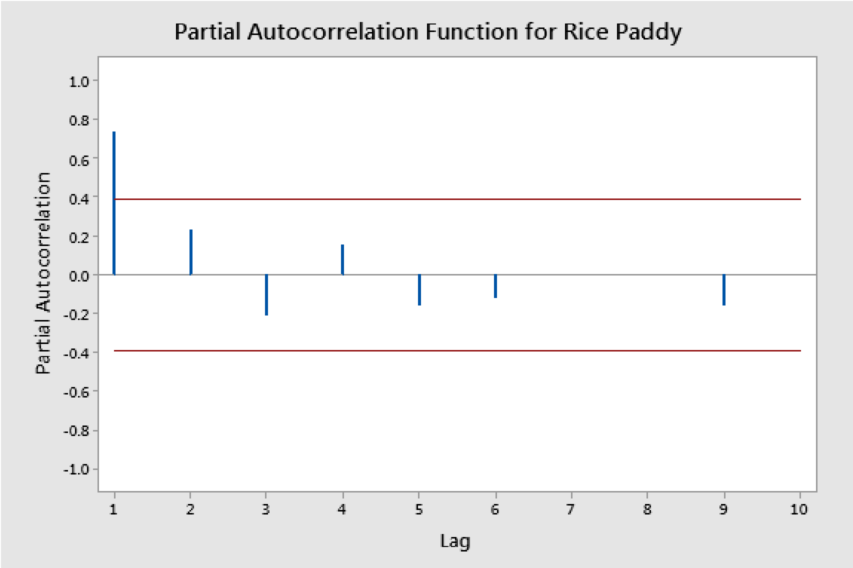

Figure 11. PACF Plot of Rice paddy Production

In the figure 11, the data has a seasonal element because the lag movement is repeating. In lag 2 which increases as well as in lag 4 and the lag that decreases from the previous lag is spotted in lag 3 and lag 5 and so does lag 6.

Based on the results of testing the trend and seasonal elements on rice paddy production data, the selection of the appropriate exponential smoothing solution method is winter exponential smoothing.

a. Determining the Smoothing Constant Value α, γ, and β

The smoothing constant used in the winter exponential smoothing model is α, γ,and β. The optimal constant value is selected based on the smallest MAPE value. The following is the MAPE value of some of the best smoothing constant values.

Table 7. Value of Constants and MAPE

No	α	γ	β	MAPE(%)
1	0.8	0.9	0.1	8.25
2	0.8	0.8	0.1	8.26
3	0.7	0.7	0.1	8.31
4	0.7	0.8	0.1	8.23
5	0.7	0.7	0.1	8.27
6	0.7	0.9	0.1	8.20
7	0.7	0.6	0.1	8.31
8	0.8	0.6	0.1	8.36
9	0.7	0.5	0.1	8.34
10	0.9	0.1	0.1	8.27

In The table 7, it can be seen that the smoothing constant value which has the smallest MAPE value is $\alpha = 0{,}7, \gamma = 0{,}9$,$\beta = 0{,}1$ and the smallest MAPE value is 8.20%. The smoothing constant value will be used in the mathematical model of winter exponential smoothing in order to obtain forecasting results for the future period.

The forecasting results for rice paddy production can be seen in the table 8.

Table 8. Estimation of rice paddy production yield in the next 5 years using winter exponential smoothing method

Year	Rice paddy Production Forecasting Results
2021	1625925
2022	1645196
2023	1687667
2024	1605530
2025	1555213

The estimation results show that rice paddy production has an average increase of 1.88% from 2021 to 2023. However, rice paddy production has decreased by an average of 4% from 2023 to 2025.

Figure 12 shows the plot results between the actual data and forecasting data using the winter exponential smoothing method. Based on the figure, it has been shown that the MAPE value generated for forecasting rice paddy production is 7.74% and less than 10%. This means that the average percentage error between the actual value and the forecast value using the winter exponential smoothing method is very small. Therefore, it is fair to say that the winter exponential smoothing method provides better forecasting value for forecasting the rice paddy production in Aceh.

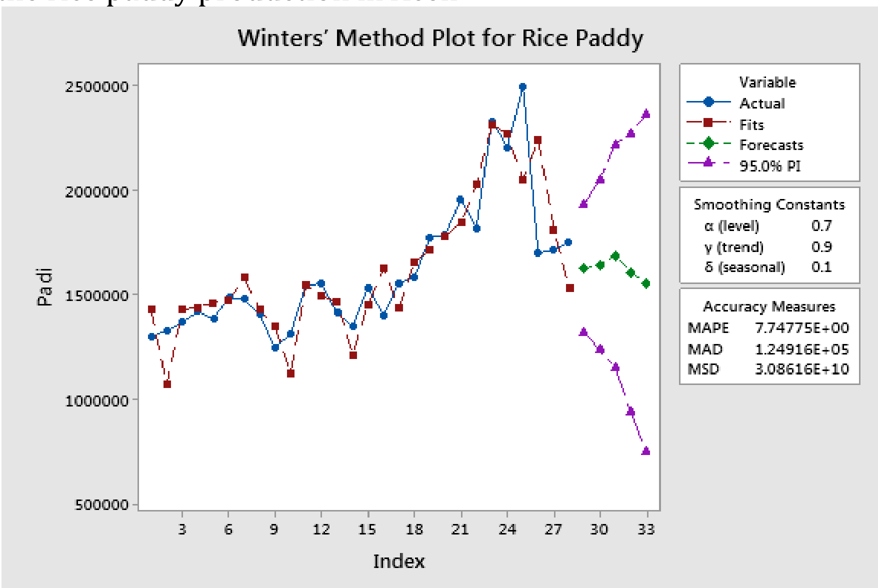

Figure 12. Plot between actual data and estimated data using Winter Method

Comparison of Estimated Results of Rice paddy Production Using the ARIMA and Winter Exponential Smoothing Models

Comparison of the estimation results of rice paddy production in the next 5 years using the ARIMA and Winter Exponential Smoothing models can be seen in the following table:

Table 9. Comparison of Estimated Results of Rice Paddy Production Using ARIMA (3,1,1) and Winter Exponential Smoothing Model

Year	Estimated Results	
	ARIMA (3,1,1)	Winter Exponential Smoothing
2021	2453401	1625925
2022	2154784	1645196
2023	2111594	1687667
2024	1615171	1605530
2025	2062436	1555213
MSE/MAD	**3,34041E+10**	**3.08616E+10**

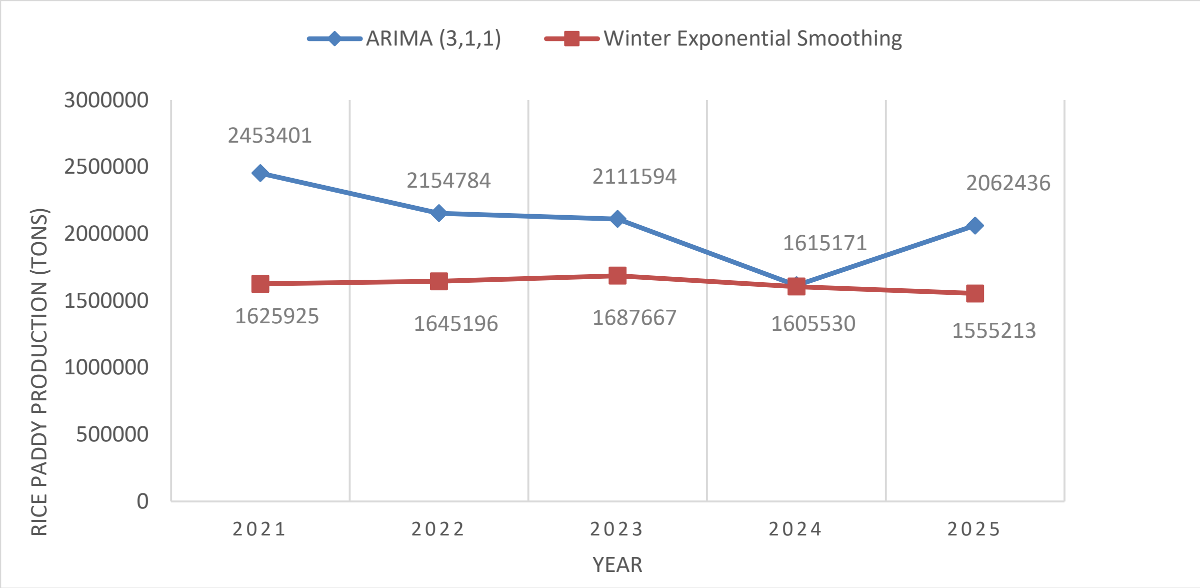

Figure 13. Comparison Graph of Rice paddy Production Estimation Results Using ARIMA(3,1,1) and Winter Exponential Smoothing Models

Based on table 9 and figure 14, the estimation results of rice paddy production using the ARIMA model have increased from 2021 to 2022 with an increased rate of 0.84%. However, the estimated production results from 2022 to 2023 have decreased with a decline rate of 5.64%. Furthermore, the results of the estimated rice paddy production have increased again by 2.14% from 2023 to 2024. In 2025, the estimated results of rice paddy have decreased by 0.75%. While the estimation results using the Winter Exponential Smoothing model show that rice paddy production has an average rate of increase of 1.88% from 2021 to 2023 and has decreased with an average decline of 4% from 2023 to 2025.

Meanwhile, for testing the estimation results, the ARIMA model (1,1,3) produces an MSE/MAD value of $3{,}34041 \times 10^{10}$, while the winter exponential smoothing model produces an MSE/MAD value of 3.08616×10^{10}. The best model is the model that has the smallest MSE/MAD value. Therefore, it can conclude that the Winter Exponential Smoothing model is the best model that can explain the actual data pattern and is used to estimate rice paddy production in Aceh.

CONCLUSIONS

The estimation results of rice paddy production of Aceh in the next five years by using ARIMA (3,1,1) model, respectively 2453401; 2154784; 2111594; 1615171; and 2062436 with the MSE/MAD $3{,}34041 \times 10^{10}$. While the estimation results using the Winter Exponential Smoothing model, respectively 1625925; 1645196; 1687667; 1605530; and 1555213 with the MSE/MAD 3.08616×10^{10}.Therefore, it can conclude that the Winter Exponential Smoothing model is the best model that can explain the actual data pattern and is used to estimate rice paddy production in Aceh.

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