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## **Time Series Forecasting Using Holt-Winters Exponential Smoothing: Application to Abaca Fiber Data**

**Abstract.** This study utilized the data on abaca fiber production and used Holt-Winters model to forecast the abaca fiber production since the studied variable is characterized by a fairly strong intensity of seasonality. For the construction of forecasts, additive and multiplicative models were used. The most accurate forecasts were selected on the basis of Mean Square Error, Root Mean Square Error, Mean Absolute Percentage Error, and Mean Absolute Scaled Error. It was found that the multiplicative method had a higher accuracy, hence it was utilized to forecast the production for the next three years. According to the findings, the anticipated fiber production for 2021-2023 showed an increase up to the second quarter, but then declining afterwards.

**Key words:** abaca fiber, time series, forecasting, Holt-Winters method

**JEL Classification:** Q1, C1

### **Introduction**

Abaca (*Musa textilis*) is a close relative of the banana. Abaca is a leaf fiber, composed of long slim cells that form part of the leaf's supporting structure. This plant is native to the Philippines and widely distributed in the humid tropics. It is also cultivated in other Southeast Asian countries with Ecuador as the second largest producing country next to the Philippines (Food and Agriculture Organization, 2021).

The Philippine abaca industry was a key player in the global abaca market (Research and Markets, 2015). The Philippines supplies 80 percent of the world's abaca need. It has become a source of employment for more than 1.5 million Filipinos who rely on it for a living, either directly or indirectly (Far Eastern Agriculture, 2020).

According to Food and Agriculture Organization (2021), abaca is prized for its great mechanical strength, resistance to saltwater damage, and long fiber length. It is used for specialty papers such as currency notes, tea and coffee bags, vacuum bags, cigarette filter paper, sausage casing paper, and high-quality writing paper. It is also used to make twines, ropes, and fishing lines and nets. Abaca has a high potential to substitute glass fibers in multiple automotive parts.

Almost all abaca produced is exported, primarily to Europe, Japan, and the United States. With this, there is a growing demand for abaca on the global market yet the current production level is not sufficient to meet this. Weather disturbances and the threat of bunchy top disease, which has wiped out the abaca sector, are among the reasons for the low production. In fact, there is a demand-supply gap in 2019 estimated to be 25,000 metric tons (Waller & Wilsby, 2019). With the rising demand for abaca fiber and the existing challenges

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being faced by the abaca sector, proper planning by responsible agencies is required to improve its production and be able to meet the global demand for abaca. Appropriate planning is required to organize their work and provide the resources they will need in the future. With this, production estimates should be known through statistical forecasting techniques in order to plan appropriately. We can provide reliable inputs to planning when we have accurate predictions or trends on abaca production.

There are a number of time series forecasting methods such as ARIMA, TBAT, Facebook's Model Prophet and many others. The choice of algorithm depends on the problem since not all procedure are applicable to the available data set. The appropriate time series model will depend upon the characteristics of data.

This paper develops a predictive model of Holt-Winters method after testing the accuracy of additive and multiplicative HW models. Using the selected model, the quarterly production of abaca for the years 2021 to 2023 is predicted. The goal of the study is to provide information on future abaca production trends for the next three years using Holt-Winters that the government bodies may utilize as they decide on policy decisions that will help the abaca sector improve. As a result, this research helps to establish more initiatives that may also have an impact on the welfare of abaca farmers. This study also contributes to the growing literature of abaca studies.

## Literature Review

Time Series Analysis is the most widely used field of data science and machine learning, it is a type of predictive analysis that forecasts the value of a variable in future occurrences based on history (Analytics Vidhya, 2022). A time series is a collection of observations of well-defined data items obtained through repeated measurements over time (Australian Bureau of Statistics, 2022). There are a number of time series forecasting methods but the choice of algorithm depends on the business problems and the data set at hand. Not all procedure are applicable to the available data set. The appropriate time series model will also depends upon the characteristics of data.

ARIMA and SARIMA models was used to predict influenza in 2012 (Song, 2016). Gecili et al. (2021) applied four time series models (Holt, ARIMA, TBATS, and cubic smoothing spline model) to publicly available daily COVID-19 data for both the USA and Italy. Liu et al. (2020) used Bayesian time-series framework to predict the number of COVID-19 infection cases in USA. Satrio et al. (2021) utilized Facebook's Prophet Model and the ARIMA model to forecast the trend of the COVID19 diseases in Indonesia. The COVID-19 pandemic in Saudi Arabia was analyzed using modified singular spectrum analysis or SSA (Alharbi, 2021). Least Square Method, Moving Average Method, Single Exponential Method, Double Exponential Method and Winter's Method were used in forecasting agricultural products prices (Ruekkasaem L. and Sasananan M., 2018)

However this paper mainly focuses on using Holt-Winters Exponential Smoothing in time series forecasting. Holt-Winter's Exponential Smoothing as named after its two contributors: Charles Holt and Peter Winter's is one of the oldest time series analysis techniques which takes into account the trend and seasonality while doing the forecasting (Solar Winds Worldwide, 2021). HW method is used for short term forecasts (Goodwin, 2010). Depending on the type of seasonality, it can either be additive or multiplicative. According to Mgale et al. (2021), forecasts will depend on three components of seasonal time

series: its level, its trend and its seasonal coefficient. Exponential smoothing is a method to smooth a time series where it allocates exponentially decreasing weights and values in opposition to historical data to lessen the value of the weights for the bygone data. Exponential smoothing can be classified into three types. While the simple or single exponential smoothing time series forecasting for uni-variate data does not have any systematic structure with no trend and seasonality. In this case, only single parameter  $\alpha$  is used as a smoothing factor that lies between 0 and 1. A smaller value  $\alpha$  designate slow learning, takes more past observations for forecasting and a larger value designate faster learning takes most recent observations for making a forecast. Next type is double exponential smoothing where apart from  $\alpha$ , another smoothing parameter  $\beta$  is used for change in trend. There are two types of the trend such as additive trend which gives linear trend analysis and the other is multiplicative trend gives exponential trend analysis. Finally, triple exponential smoothing adds seasonality ( $\lambda$ ) part from  $\alpha$  and  $\beta$ .

There are various studies on time series forecasting that used Holt-Winters method. Lima et al. (2019) uses Holt-Winters Exponential Smoothing in forecasting economic time series and compares the accuracy of additive and multiplicative models. Panda (2020) predicts the spreading of COVID-19 from Indian and its states using ARIMA and Holt-Winters. Kuzmin et al (2017) employed the Holt–Winters Model to forecast and assess the efficiency of the methods used to plan a firm’s sales in the upmarket sector. Ribeiro (2019) evaluate both Holt-Winter’s additive and multiplicative time series model to forecast the Brazilian natural gas production.

## Methodology

### Data sources

This study utilizes secondary data obtained from the website of Philippine Statistics Authority or PSA. Specifically, the quarterly production of abaca fiber in Eastern Visayas region covered a period of 7 years starting from 2014 to 2020, (see Table 1).

Table 1. Quarterly abaca fiber production in Eastern Visayas (2014-2020)

| Year | Quarter |         |         |         |
|------|---------|---------|---------|---------|
|      | Q1      | Q2      | Q3      | Q4      |
| 2014 | 2856.65 | 3977.72 | 3317.62 | 2697.26 |
| 2015 | 2825.97 | 3856.02 | 3326.67 | 2743.93 |
| 2016 | 2516.62 | 3810.31 | 3311.15 | 2854.53 |
| 2017 | 2572.09 | 3780.17 | 3267.92 | 3050.89 |
| 2018 | 2575.98 | 3728.62 | 3227.52 | 3017.21 |
| 2019 | 2625.73 | 3695.56 | 3275.68 | 3016.46 |
| 2020 | 2244.27 | 3574.54 | 3284.62 | 3032.95 |

Source: Philippine Statistics Authority.

### Data analysis

Using the data, future values will be generated using Holt-Winters method. This technique produces exponentially smoothed values for the level of the forecast, the trend, and the seasonal adjustment to the forecast. The forecast will depend on the following three components. These three smoothing equations are:

Level: the average value in the series.

| <b>Additive HW Method</b>                                 | <b>Multiplicative HW Method</b>                               |
|---|---|
| $\alpha(Y_t - s_{t-s}) + (1 - \alpha)(l_{t-1} + b_{t-1})$ | $l_t = \alpha(y_t/s_{t-s}) + (1 - \alpha)(l_{t-1} + b_{t-1})$ |
| $0 \leq \alpha \leq 1$                                    | $0 \leq \alpha \leq 1$  |

*Trend*: the increasing or decreasing value in the series.

| <b>Additive HW Method</b>                         | <b>Multiplicative HW Method</b>                   |
|---|---|
| $b_t = \beta(l_t - l_{t-1}) + (1 - \beta)b_{t-1}$ | $b_t = \beta(l_t - l_{t-1}) + (1 - \beta)b_{t-1}$ |
| $0 \leq \beta \leq 1$                             | $0 \leq \beta \leq 1$                             |

*Seasonality*: the repeating the short-term cycle in the series.

| <b>Additive HW Method</b>                       | <b>Multiplicative HW Method</b>                    |
|---|--|
| $s_t = \gamma(y_t - l_t) + (1 - \gamma)s_{t-s}$ | $s_t = \gamma \frac{y_t}{l_t} (1 - \gamma)s_{t-s}$ |
| $0 \leq \gamma \leq 1$                          | $0 \leq \gamma \leq 1$                             |

Where  $s_t$  is the seasonality,  $l_t$  is the series level,  $b_t$  is the trend component,  $y_t$  is the observed value and  $\alpha$ ,  $\beta$ , and  $\gamma$  are the smoothing factor of level, trend and seasonality respectively.

Holt-Winters methods describe two distinct models that depend on the behavior of the initial series which is based on the analysis of linear trend and seasonality component (Pelegrini & Fogliatto, 2002). Holt-Winters exponential smoothing model can either be a multiplicative or additive model. The choice of the model depends on the seasonal component of the series (Mgale, 2021):

- a) In Holt-Winters additive method, seasonal pattern of a series has a constant amplitude. Seasonal changes in the data stay roughly the same over time and don't fluctuate in relation to the overall data. This method is best for data with trend and seasonality that does not increase over time (Hyndman et al., 2021)

The HW additive model equation is given by:

$$Y_t = T_t + S_t + \varepsilon_t$$

- b) In Holt-Winters multiplicative method, multiplies the trended forecast by the seasonality. This method is best for data with trend and seasonality that increases over time. It results in a curved forecast that reproduces the seasonal changes in the data (Winters, 1960).

The HW multiplicative model equation is given by

$$Y_t = T_t \times S_t \times \varepsilon_t$$

Where  $T_t$  represents the trend,  $S_t$  is the seasonal component, and  $\varepsilon$  is the error term

The following procedures were performed in extrapolating quarterly production of abaca fiber in Eastern Visayas region:

1. *Decomposition:* This method was applied to separate the seasonality, trend, and error component of a seasonal time series. A comparison was done to determine whether an additive or multiplicative Holt-Winters model will be used in prediction. Several error measures were employed to evaluate the performance in the selection of the Holt-Winters Model, including RMSE, MSE, MAPE, and MASE.
2. *Fitting the model and prediction:* After the model was identified and all of the parameters were determined, the model was used to forecast future values.
3. *Forecasting evaluation:* Diagnostic checks were carried out to ensure reliability. Residual analysis was performed whether a model has adequately captured the information in the data. The residuals are equal to the difference between the observations and the corresponding fitted values.

$$e_t = y_t - \hat{y}_t$$

A good forecasting method will yield residuals with the following properties for it to be declared a fitted model:

1. The residuals are uncorrelated. The Ljung-Box Test indicates the presence of these correlations. If the p-value > 0.05, there is a 95% chance the residuals are independent.
2. The residuals have zero mean.
3. The residuals have constant variance.
4. The residuals are normally distributed.

R version 3.02 will be used for data entry and data analysis such fitting the time series, predicting, and diagnostic testing.

## Results and discussion

### Preliminary data analysis

Eastern Visayas was the top abaca fiber producer with 3.34 thousand metric tons or 21.3 percent share of the total production in the 3rd quarter of 2021 (PSA, 2021). In 2020, the volume of abaca produced in the Philippines amounted to approximately 71 thousand metric tons (Statista Research Department, 2020). With abaca as the strongest fiber in the world, the Philippines supplies 87.5 % of the world's requirement for abaca fiber and as such is the number one supplier worldwide (Philippines General Consulate - Vancouver, Canada, 2020). Hence abaca industry has a significant contribution to the Philippine economy. Figure 1 illustrates the abaca fiber production of Eastern Visayas region starting from 2014 until 2020. According to PSA, there is a high and steady fiber production since 2010 until 2013. However, in 2014 a significant drop in abaca fiber production occurred until 2020. When the super typhoon Yolanda, also known as Haiyan, devastated the provinces of Eastern Visayas in November 2013, it wiped off abaca plantations, resulting in a drop in abaca fiber supply in the region. In addition, the abaca bunchy top virus wreaked havoc on the business, wiping out thousands of hectares of abaca. Figure 2 reflects that the time series of abaca fiber output demonstrated a periodic up and down movement around the current level or known as seasonality, with a peak in the second quarter of the year.

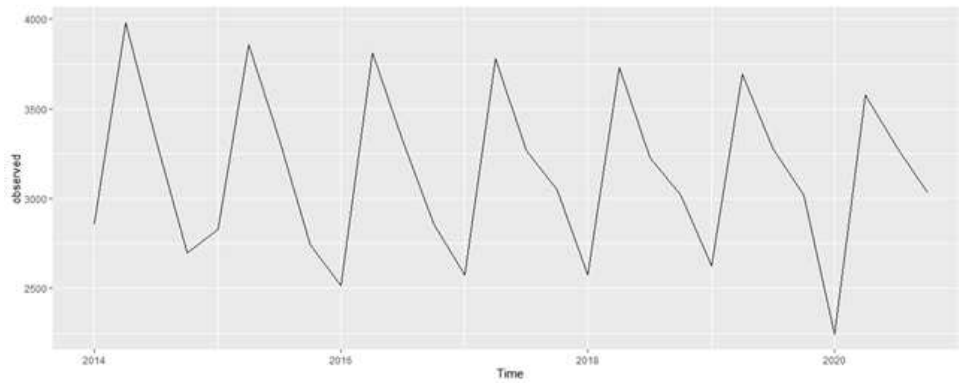


Fig. 1. Time series of abaca fiber production in Eastern Visayas (2014-2020)

Source: own Authors' calculations.

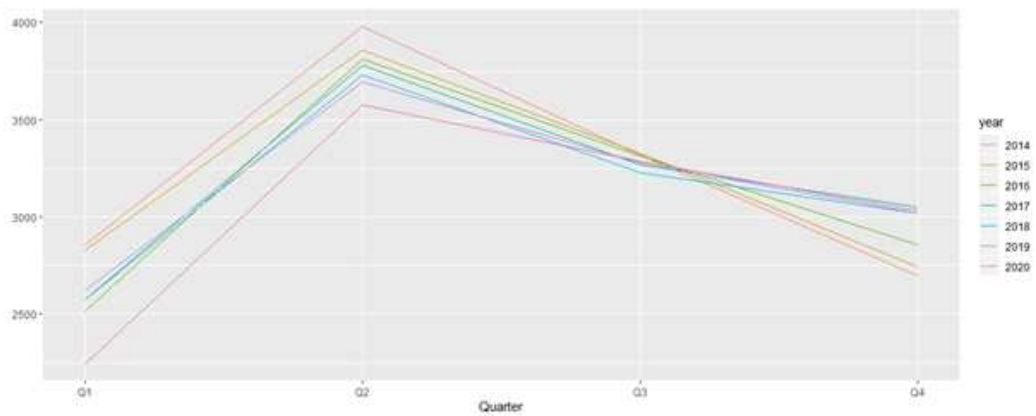


Fig. 2. Seasonal time series plot of abaca fiber production in Eastern Visayas (2014-2020)

Source: see table 1.

## Decomposition

Seasonality, trend, and error are the three components of a seasonal time series. These three time series components were decomposed in Figure 3. The original time series (top), the estimated trend component (second from top), the estimated seasonal component (third from top), and the estimated irregular component (fourth from top) are all shown in the graph below.

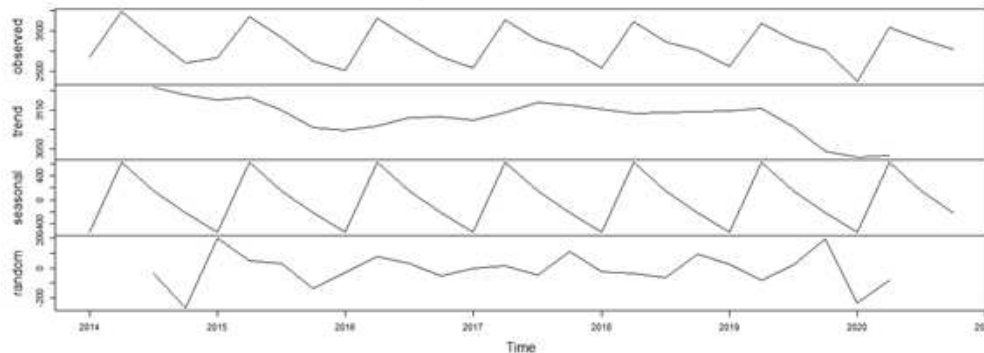


Fig. 3. Decomposition of time series data on abaca fiber production in Eastern Visayas (2014-2020)

Source: see table 1.

### Holt-Winters Method Analysis: Additive and Multiplicative

Holt-Winters time series model can either be of additive or multiplicative seasonality. With additive model, the behavior is linear where changes over time are consistently made by the same amount, like a linear trend. In this situation, the linear seasonality has the same amplitude and frequency. The work of Rahman et al. (2016) focused on the analysis of seasonal time series data using additive and multiplicative seasonal model of Holt-Winters method and forecast the monthly revenue using additive HW as the best model. Also in the previous research of Nurhamidah et al. (2020), it predicted seasonal time series data using the Holt-Winter exponential smoothing additive model using the number of passengers departing at Hasanudin Airport in 2009-2019 as the data.

Table 2. Initialization of level, trend, seasonal and exponential smoothing parameters of the additive and multiplicative HW model for the abaca fiber production time series data

| Parameters     | Additive  | Multiplicative |
|----------------|-----------|----------------|
| $\hat{\alpha}$ | 1e-04     | 0.0268         |
| $\hat{\beta}$  | 1e-04     | 1e-04          |
| $\hat{\gamma}$ | 0.8132    | 0.9592         |
| $\hat{l}_1$    | 3332.2488 | 3350.8505      |
| $\hat{b}_1$    | -9.6558   | -8.4428        |
| $\hat{s}_1$    | -220.1674 | 0.8487         |
| $\hat{s}_2$    | 148.9338  | 1.0334         |
| $\hat{s}_3$    | 623.2483  | 1.2279         |
| $\hat{s}_4$    | -552.0148 | 0.89           |

Source: Author’s calculation and analysis (2022).



On the other hand, the multiplicative model has an increasing or decreasing amplitude and/or frequency over time. The study of Koehler et al. (1999) deals with Forecasting Models and Prediction Interval for the Multiplicative Holt-Winters Method. Found in Table 2 are the smoothing constants estimates and the values used for the initialization of both multiplicative and additive methods.

Table 3 shows the values comparing the performance of two Holt-Winters models. It should be noted that the lower weights produce a smoother line, and the larger ones a more accentuated line. Thus, a smaller weights for a noisy data gives values that do not fluctuate along with noise

Table 3. Forecasting performance evaluation of HW models of abaca fiber production in Eastern Visayas

| <b>Error Measures</b>                 | <b>Additive</b> | <b>Multiplicative</b> |
|---------------------------------------|-----------------|-----------------------|
| Mean Square Error (MSE)               | 12.65501        | 7.720112              |
| Root Mean Square Error (RMSE)         | 327.4811        | 275.261               |
| Mean Absolute Percentage Error (MAPE) | 6.857743        | 5.840228              |
| Mean Absolute Scaled Error (MASE)     | 0.9293798       | 0.7780083             |

Source: Author's calculation and analysis (2022).

The study of Gundalia and Dholakia (2012) examines the performance of the Holt-Winters method in predicting the maximum and minimum daily temperature time series using the three standard error measures MSE, MAPE and MAD. In this section, the comparison of two models, additive and multiplicative, using MSE, RMSE, MAPE AND MASE as error measures.

Figures 4 and 5 illustrates the plots of additive and multiplicative seasonality and the variation between two plots are visible. Based on the four measures of evaluation (see Table 3), multiplicative method has a better performance than additive method since it has a lower MSE, RSME, MAPE, and MASE. This is in parallel to the study of Lima et al. (2019) as it compares the accuracy of additive and multiplicative Holt-Winters method using e commerce retail sales.

Hence, in predicting abaca fiber production Holt-Winters model with multiplicative seasonality was used. This model was utilized to estimate abaca fiber production from 2021-2023.

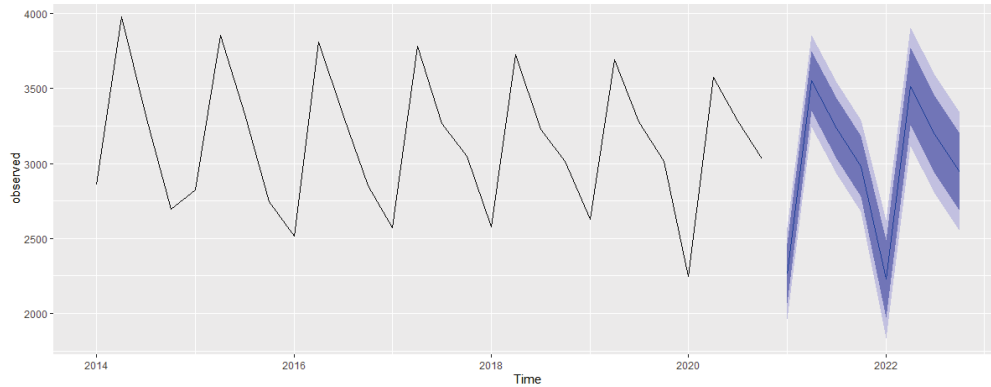


Fig. 4. Forecasts on abaca fiber production using Holt-Winters additive method

Source: see table 1.

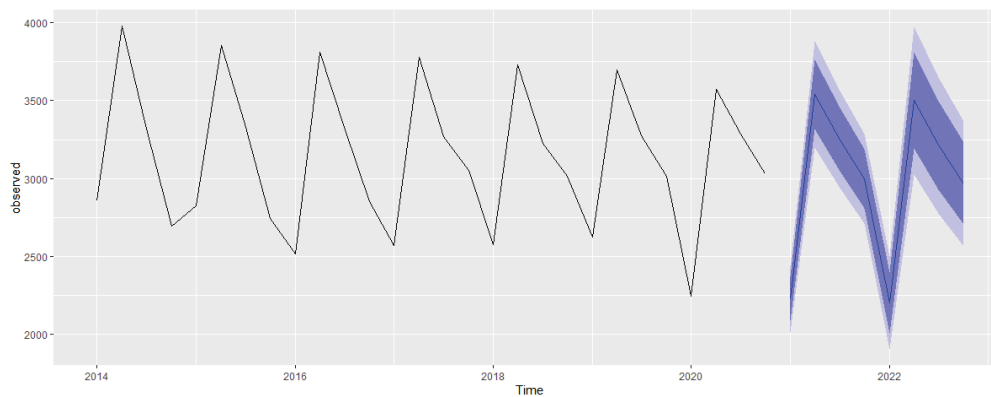


Fig. 5. Forecasts on abaca fiber production using Holt-Winters multiplicative method

Source: see table 1.

## Predictions

By Holt-Winters multiplicative model, forecast values of abaca fiber production was generated. Table 4 presents the forecasts values of abaca fiber production in Eastern Visayas for the next three years or 12 quarters, starting 2021 until 2023. As plotted in Figure 6, we notice that during the 1st quarter (January to March) production of abaca fiber is quite low. During the 2nd quarter (April to June), abaca fiber production is at its peak while there is a slight reduction in the 3rd quarter (July to September) and continues to reduce during the 4th quarter. Figure 7 confirms the seasonality of the time series data using seasonal plots.

Table 4. Forecasts values on abaca fiber production in Eastern Visayas Region (2021-2023)

| Year | Q1       | Q2       | Q3       | Q4       |
|------|----------|----------|----------|----------|
| 2021 | 2207.241 | 3537.511 | 3247.591 | 2995.921 |
| 2022 | 2170     | 3500     | 3210     | 2958     |
| 2023 | 2133     | 3463     | 3173     | 2921     |

Source: Author’s calculation and analysis (2022).

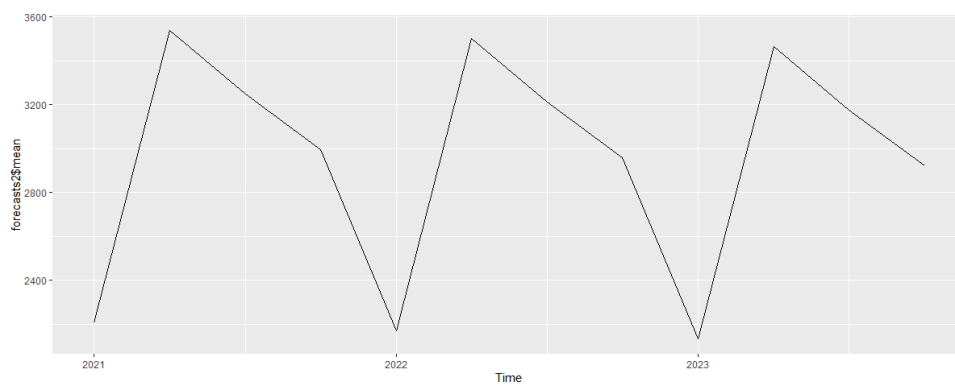


Fig. 6. Forecasts on abaca fiber production in Eastern Visayas Region (2021-2023)

Source: see table 1.

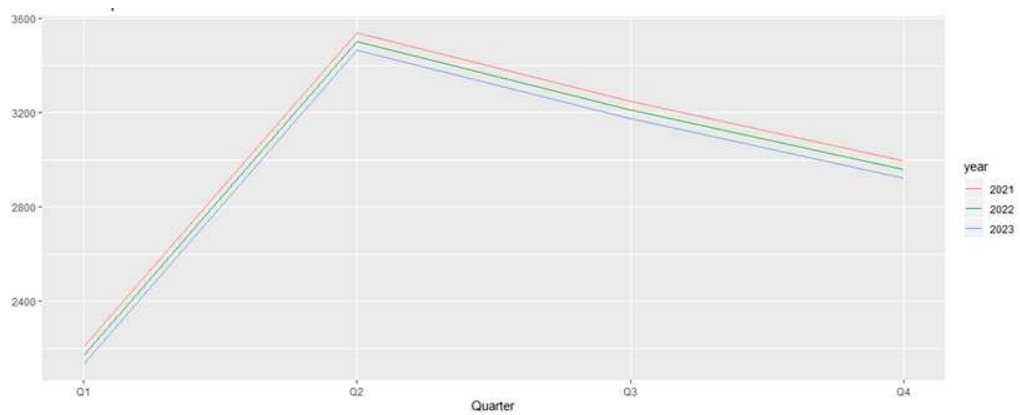


Fig. 7. Seasonal plot of the forecasted values (2021-2023)

Source: see table 1.

## Forecast Evaluation

We need to check whether the model has appropriately captured the information in the data. To do this, residuals were verified if they are uncorrelated for each time point, if it has a mean of zero, a constant variance and is normally distributed. By visual inspection (see Figure 8), the plot shows that the distribution of forecast errors is roughly centered on zero, has a constant variance and is more or less normally distributed. By Ljung-Box, the presence of correlations in residuals was checked. Based on the results of the test, the p-value is less than 5% ( $X^2 = 18.15$ ,  $df = 20$ ,  $p\text{-value} = 0.5776$ ) and implies that there is a 95% chance the residuals are independent. The Ljung-Box test showed that there is little evidence of non-zero autocorrelations in the in-sample forecast errors, and the distribution of forecast errors seems to be normally distributed with mean zero.

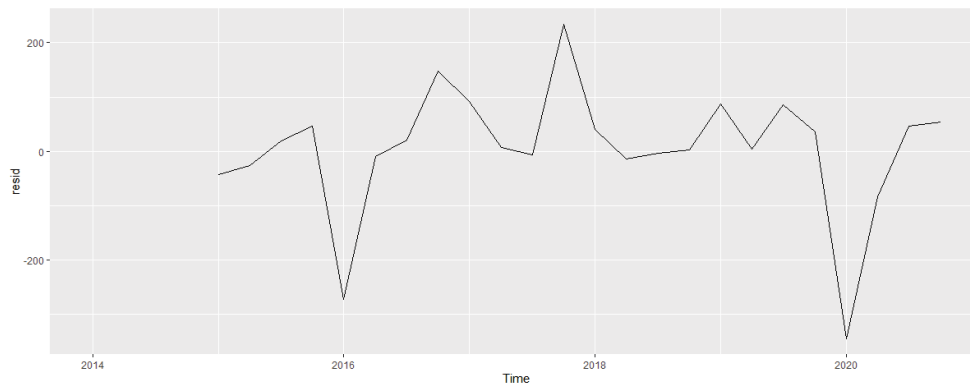


Fig. 8. Forecast errors for abaca fiber production

Source: see table 1.

## Conclusions and recommendations

After both multiplicative and additive models were evaluated and compared using several error measures, we may infer that the multiplicative method performed well and was utilized in subsequent production predictions. Based on the predicted values, a major decline in abaca fiber production happens after the second quarter throughout the year. Overall, there is a downward trend of abaca fiber production. As a result of the forecasted values, abaca farm rehabilitation is highly suggested in order to boost abaca fiber production in the region. Government subsidies, specifically on plantlets and other abaca farming inputs, are recommended. Extension services must also be made available to abaca farmers, particularly in the fight against the abaca bunchy top virus, and proper monitoring must be done regularly to the farmers. It is highly suggested to conduct needs assessment survey among the abaca farmers in order to understand their challenges and identify their specific needs related to abaca farming. Added to this is the need to conduct baseline survey on abaca farm households to assess the impact of projects implemented (e.g. subsidies) especially on their incomes.

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