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ESTIMATION OF COCONUT HARVEST YIELDS IN NORTH MALUKU PROVINCE USING THE ADAMS-BASHFORTH-MOULTON METHOD

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Abstract

The present research applies the Verhulst growth model and the Adams-Bashforth-Moulton numerical method to estimate coconut harvest yields in North Maluku Province. Using coconut harvest data from 2019 to 2023 obtained from Badan Pusat Statistika (BPS), the model was initialized through the fourth-order Runge-Kutta method to generate four initial values. These values were then used in the ABM method to predict yields for the period 2024 to 2033. The simulation results show a slow growth in harvest yields from 2024 to 2026, with an average increase of approximately 0.003% per year, followed by a significant increase in 2027. After that, the harvest yields stabilize near the carrying capacity of approximately 432,600 tons. In contrast, a notable decrease of 1.923% in coconut harvest yields was observed between 2022 and 2023, highlighting fluctuations prior to stabilization and confirming the characteristic behavior of the Verhulst model in modeling population or production dynamics. The results of this study can serve as a foundation for more effective agricultural production planning, supply chain optimization, and the formulation of food security policies in North Maluku Province. By understanding the growth patterns of harvest yields, local governments and industry stakeholders can design more targeted distribution and investment strategies.

Keywords: *Adams Bashforth Moulton Method, Coconut Harvest Results, Fourth-order Runge-Kutta method, Numerical Method, Verhulst Model*

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1. INTRODUCTION

Coconut is one of the major agricultural commodities in Indonesia, playing a strategic role in supporting the national economy, particularly in coastal and island regions. Indonesia is recognized as one of the largest coconut producers in the world, with millions of farmers relying on this crop as their primary source of livelihood. In North Maluku Province, coconut cultivation has become an integral part of local agricultural activities and is considered a leading regional commodity. Coconut is a characteristic plant that grows in tropical regions. It has a wide range of benefits and serves as one of the primary export commodities in three main forms: fresh coconuts, coconut oil, and dried coconut (copra). Coconut oil, in particular, holds high economic value, making coconuts a major commercial commodity. Indonesia, as one of the largest coconut producers in the world, produces approximately 18.30 million tons of coconuts annually and holds a market share of 30.24% of global production **[1]**.

Coconuts play a significant role in the Indonesian people's economy, as evidenced by the fact that the majority of coconut plantations are managed by smallholder farmers. Approximately 96.60% of coconut plantations are managed by farmers, with an average landholding of one hectare per family. This illustrates the importance of coconuts as a driver of economic activity for Indonesian communities **[2]**. Therefore, efforts to develop coconuts into high-value economic products have the potential to improve community welfare and contribute to national economic growth. Currently, Indonesian coconut products are generally traded in the form of fresh coconuts, copra, or coconut oil. Increasing the added value of coconut commodities—especially through high-value products such as copra and coconut oil—can significantly raise farmers incomes in key production areas **[3]**.

Coconuts are one of the five main commodities in North Maluku Province that have been prioritized by the provincial government for development into coconut oil products. Farmers typically process coconuts into copra, which comes in two types: white copra (sun-dried) and black copra (smoke-dried). In 2019, the North Maluku Provincial Government prepared to establish a coconut oil industry to boost the local economy. The Department of Industry and Trade (Disperindag) planned to upgrade copra processing technology into coconut oil, even if only at a small industrial scale. The government also intended to shift from processing raw coconuts to using copra, as the latter is more efficient and consumes less raw material. However, the plan was temporarily halted due to the Covid-19 pandemic. In 2021, the provincial government proposed funding for procuring RBD (Refined, Bleached, and Deodorized) coconut oil machinery to help realize the development of this industry **[4]**.

To produce coconut oil in sufficient quantities, a large and stable supply of raw coconuts is essential. The production process involves extracting the coconut meat and processing it into oil, making the availability of coconuts a critical factor in sustaining the coconut oil industry. If the supply is limited, production capacity will inevitably be constrained. Therefore, increasing output depends heavily on the availability of raw materials that meet the required volume and timing of demand. Given the importance of maintaining a steady supply of coconuts, the ability to accurately estimate coconut harvest yields becomes vital. However, despite the widespread recognition of the economic value of coconut production, the application of technology in forecasting yields remains limited. Most current practices rely on traditional and intuitive methods, lacking the support of robust mathematical modeling. Yet, precise yield estimation is essential not only for ensuring sufficient raw material for processing but also for effective planning in distribution, storage, and export of coconut-based products.

To estimate the future production of coconuts in North Maluku Province, a basic understanding of differential equations is required. Differential equations are a fundamental part of mathematics closely related to real-life applications. Many problems in engineering, health sciences, and natural sciences can be modeled using differential equations [5],[6]. A differential equation is an equation that involves the derivatives of one or more unknown functions [7]. Based on the number of independent variables, differential equations can be classified as ordinary or partial [8]. Based on linearity, they can be classified as linear or nonlinear differential equations [9],[10].

Most nonlinear differential equations are difficult to solve analytically; therefore, numerical methods are often used to approximate solutions to such equations, though these numerical solutions involve a certain degree of error [11], [12]. In this study, the numerical solution of the Verhulst model. The Verhulst model is not only a logistic model but also specifically describes the growth process that is constrained by environmental capacity, which is highly relevant for agricultural commodities such as coconuts. In the context of coconut production, factors such as land limitations, natural resources, and supply capacity can restrict the growth rate of production, making the Verhulst model particularly suitable for depicting such dynamics. Furthermore, this model can illustrate the gradual production changes initially, followed by acceleration as production capacity approaches its maximum value, which is a natural characteristic of coconut production growth in regional contexts such as North Maluku. Therefore, the use of the Verhulst model provides a more realistic explanation for the fluctuations and stabilization of harvest yields in the long term. The Verhulst model, which is a nonlinear differential equation, is used to estimate coconut production in North Maluku Province. The model is first reduced into a system of two first-order differential equations so it can be solved using the Adams-Bashforth-Moulton method.

2. RESEARCH METHODS

2.1. Data and Sources

The data used in this study consists of the plantation area by regency/city and type of coconut plant in North Maluku Province for the years 2019 to 2023, published by Badan Pusat Statistik (BPS).

2.2. Research Procedure

The steps involved in solving a nonlinear differential equation numerically using the Adams-Bashforth-Moulton method are as follows [13]:

a. Determining the production rate and carrying capacity based on the plantation area data by regency/city and type of coconut plant in North Maluku Province.
b. Determining the initial values and step size, and calculating the initial solution using the fourth-order Runge-Kutta method.
c. Calculating the function values f_1, f_{n-1}, f_{n-2}, and f_{n-3}.
d. Calculating the function value f_{n+1} and correcting the value of y_{n+1} using the corrector equation.
e. Analyzing the numerical solution using the Adams-Bashforth-Moulton method.

3. RESULTS AND DISCUSSION

3.1. Initial Values of the Verhulst Model Using the 4th-Order Runge-Kutta Method for Coconut Harvest Yields in Each Regency and City in North Maluku Province

The coconut harvest data in North Maluku Province, obtained from Badan Pusat Statistik (BPS), covers the years 2019 to 2023 and will be processed to estimate coconut harvest yields for the years 2024 to 2033. The coconut harvest data referred to can be seen in the following Tabel 1.

Tabel 1. Coconut Harvest Data in 10 Regencies of North Maluku Province

Regency /City	Year				
	2019 (tons)	2020 (tons)	2021 (tons)	2022 (tons)	2023 (tons)
West Halmahera	31,571	49,271	31,671	31,671	35,586
Central Halmahera	10,121	12,900	10,221	10,121	7,153
Sula Islands	31,218	29,731	30,503	31,196	29,411
South Halmahera	29,731	15,249	29,731	29,731	20,330
North Halmahera	49,250	31,971	49,379	49,484	71,978
East Halmahera	15,249	10,121	15,297	15,385	11,013
Morotai Island	12,900	30,679	13,300	13,300	7,356
Taliabu Island	12,835	8,846	12,985	13,000	7,093
Ternate	1,808	1,080	1,080	1,080	600
Tidore Islands	8,841	12,835	8,841	9,041	9,566
Total	203,524	202,683	203,008	204,009	200,086

Source: https://malut,bps,go,id/id/statistics-table/2/MzA1IzI=/produksi-perkebunan-menurut-kabupaten-kota-dan-jenis-tanaman-di-provinsi-maluku-utara,html

Based on **Table 1**, the coconut harvest data in North Maluku Province can be summarized as follows:

Tabel 2. Coconut Harvest Data in North Maluku Province

No	Year	Total Harvest (tons)
1	2019	203,542
2	2020	202,683
3	2021	203,008
4	2022	204,009
5	2023	200,086

The coconut harvest for the next four years will then be determined using the Verhulst model with the fourth-order Runge-Kutta method. The Verhulst model is given by the following equation **[13]**:

$$f(t_n, H_n) = \frac{dH}{dt} = KH_n\left(1 - \frac{H_n}{C_c}\right) \quad (1)$$

where:

$f(t_n, H_n)$: coconut harvest yield function
K : coconut harvest growth rate
H_n : total coconut harvest yield in year n
C_c : carrying capacity

Subsequently, the coconut harvest growth rate can be determined using the following formula:

$$K = \frac{1}{t} \ln\left(\frac{H}{H_0}\right) \quad (2)$$

where H_0 is the coconut harvest in 2019, which is 203,524.
Then, by taking the value $H_0 = 203{,}524$, which is the coconut harvest in 2019, and H =202,683, the harvest in 2020, with $t = 1$, the value of K is obtained as follows

$$|K| = \left|\frac{1}{1} \ln\left(\frac{202{,}683}{203{,}524}\right)\right| \approx 0.00414$$

After obtaining the value of the coconut harvest growth rate K, the carrying capacity C_c of the coconut harvest H will now be determined. The carrying capacity is obtained using the trial-and-error method, by substituting estimated values of H into the Verhulst model [13]. Since the total coconut harvest remains below 205,000 tons, the carrying capacity is assumed to be 205,000 tons. Thus, the Verhulst model becomes:

$$f_n = f(t_n, H_n) = 0.00414 H_n \left(1 - \frac{H_n}{205{,}000}\right) \quad (3)$$

Equation (3) will be used to determine the value of H_n using the fourth-order Runge-Kutta method, as follows [14],[15]:

$$H_{n+1} = H_n + \frac{h}{6}(k_1 + 2k_2 + 2k_3 + k_4) \quad (4)$$

where

$$k_1 = f(t_n, H_n)$$
$$k_2 = f\left(t_n + \frac{h}{2}, H_n + \frac{h}{2} k_1\right)$$
$$k_3 = f\left(t_n + \frac{h}{2}, H_n + \frac{h}{2} k_3\right)$$
$$k_4 = f(t_n + h, H_n + hk_3)$$

The value of H_n will be determined only for $n = 1, 2$ and 3, which will then be considered as initial values for predicting production in the following years. Subsequently, based on calculations using MATLAB, the values of k_1, k_2, k_3 and k_4 are obtained, which will be used to determine the initial solution using the Runge-Kutta method.

Tabel 3. Results of the calculated values of k_1, k_2, k_3 and k_4 using MATLAB

t	k_1	k_4	k_3	k_4
t_1	6.067	6.054	6.054	6.042
t_2	6.042	6.030	6.030	6.017
t_3	6.017	6.005	6.005	5.993

The initial values H_1, H_2 and H_3 were obtained using the fourth-order Runge-Kutta method with a step size of $h = 1$, based on the initial value $H_0 = 203{,}524$.

Tabel 4. **The result of calculating the value of H_1, H_2 and H_3 using the fourth-order Runge-Kutta method in MATLAB**

n	t_n	H_n	f_n
1	t_1	203,530.054	6.067
2	t_2	203,536.084	6.042
3	t_3	203,542.089	6.017

The harvest results H_n, for $n = 0$ to 3, will serve as the initial values to be used in the Adams-Bashforth-Moulton method.

3.2. Solution of the Verhulst Model Using the Adams-Bashforth-Moulton Method for Estimating Coconut Harvest in North Maluku Province

After the initial values are determined, the next step is to find the numerical solution, which is the estimated coconut harvest, using the Adams-Bashforth-Moulton method. The general form of the Adams-Bashforth-Moulton method is formulated as follows [13]:

Predictor :

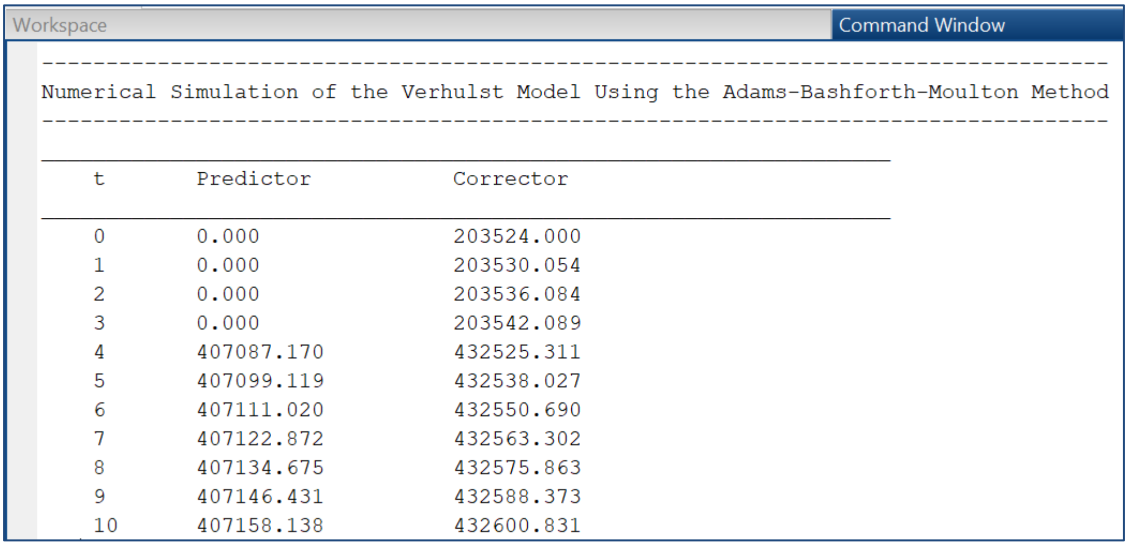
$$P_{n+1} = H_n + \frac{h}{24}(-9f_{n-3} + 37f_{n-2} - 59f_{n-1} + 55f_n) \tag{5}$$

Corrector :

$$H_{n+1} = H_n + \frac{h}{24}(f_{n-2} - 5f_{n-1} + 19f_n + P_{n+1}) \tag{6}$$

The values of H_n and f_n for $n = 0$ to 3, as obtained in Subsection 3.1, are substituted into **Equation (5)** to generate the predictor values. These predictor values are subsequently used in **Equation (6)** to compute the corrected value of H_{n+1}.

Based on the calculations performed using MATLAB, the numerical solution obtained through the Adams-Bashforth-Moulton method is used to predict coconut harvest yields in North Maluku Province for the years 2024 to 2033, as follows:


Workspace | Command Window

Numerical Simulation of the Verhulst Model Using the Adams-Bashforth-Moulton Method

t	Predictor	Corrector
0	0.000	203524.000
1	0.000	203530.054
2	0.000	203536.084
3	0.000	203542.089
4	407087.170	432525.311
5	407099.119	432538.027
6	407111.020	432550.690
7	407122.872	432563.302
8	407134.675	432575.863
9	407146.431	432588.373
10	407158.138	432600.831

Figure 1. **The results of the numerical solution of the Verhulst model using the Adams-Bashforth-Moulton method, computed with MATLAB**

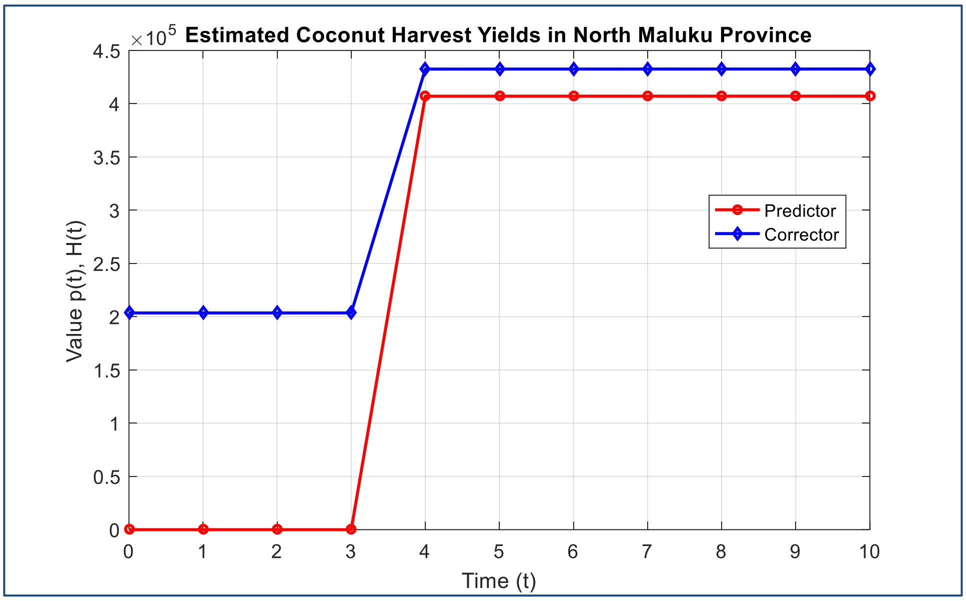


Figure 2. Visualization of the Numerical Solution Using the Adams-Bashforth-Moulton Method for Coconut Harvest Estimation in North Maluku Province

The figure presents the numerical simulation results of the Verhulst model using the Adams-Bashforth-Moulton method to estimate coconut harvests in North Maluku Province from 2023 to 2033. Initial values from t_0 to t_3 were calculated using the fourth - order Runge-Kutta method and then applied in the Adams-Bashforth-Moulton method to compute the predictor and corrector values starting from year four. The graph shows a sharp increase in harvest estimates at t_4, which then levels off and stabilizes near the carrying capacity of approximately 432,600 tons, as reflected in the corrector values. The difference between the predictor and corrector curves indicates that the corrector provides a more accurate and refined estimation of the Verhulst model solution.

The corrector values from t_4 to t_{10} in Figure 2 represent the solution of the Verhulst model, which illustrates the estimated coconut harvest in North Maluku Province. The detailed estimation results can be found in Table 5.

Tabel 5. Estimated Coconut Harvest in North Maluku Province for the Years 2024–2033

Year	Total Harvest (tons)
2024	203,530
2025	203,536
2026	203,542
2027	432,525
2028	432,538
2029	432,551
2030	432,563
2031	432,576
2032	432,588
2033	432,601

Table 5 presents the estimated coconut harvest in North Maluku Province for the period 2024 to 2033, based on the numerical solution of the Verhulst model. In the first three years (2024–2026), the total harvest remains relatively stable at around 203,530–203,542 tons, indicating the initial slow growth phase. However, in 2027, there is a significant increase to 432,525 tons, reflecting the rapid growth phase described by the Verhulst model before reaching the carrying capacity. From 2028 onward, the harvest values increase very slightly and steadily each year, reaching 432,601 tons by 2033, indicating that the system is approaching the maximum coconut harvest capacity in the province.

Tabel 6. Estimated Increase or Decrease in Coconut Harvest from 2019 to 2033 in North Maluku Province

Year	Increase/Decrease in Harvest (tons)	Percentage (%)
2019-2020	859	0.422 ↓
2020-2021	325	0.16 ↑
2021-2022	1001	0.493 ↑
2022-2023	3923	1.923 ↓
2023-2024	3444	1.721 ↑
2024-2025	6	0.003 ↑
2025-2026	6	0.003 ↑
2026-2027	228983	*significant increase*
2027-2028	13	0.003 ↑
2028-2029	13	0.003 ↑
2029-2030	12	0.003 ↑
2031-2032	13	0.003 ↑
2032-2033	12	0.003 ↑

Table 6 presents the estimated increase or decrease in coconut harvest yields in North Maluku Province from 2019 to 2033, expressed in both tons and percentage. The data show fluctuations in harvest yields during the early years, including a sharp decline of 1.923% in 2022–2023 and a significant increase in 2026–2027. After 2027, harvest growth exhibits a very small but consistent trend, approximately 0.003% per year. This pattern reflects a transition from a rapid growth phase to a stable phase, which is a typical characteristic of the Verhulst model in modeling population or production dynamics. The sharp decline of 1.923% in 2022–2023 is a significant finding that warrants deeper interpretation, as this fluctuation may indicate real-world challenges faced by the coconut farming sector in North Maluku, such as extreme weather conditions (e.g., prolonged drought or heavy rainfall), pest outbreaks, or market dynamics that affect farmers' motivation and capacity to manage coconut plantations. Although the Verhulst model theoretically illustrates a natural system transition, the drastic decline during that period cannot be fully explained by the mathematical approach alone, as it is likely influenced by external factors not included in the numerical calculation. Therefore, future research is recommended to incorporate supporting data such as climate conditions, market prices, and agricultural policies in effect during the relevant period in order to enrich the analysis and enhance the relevance of the findings for stakeholders in the coconut industry.

4. CONCLUSION

Based on the numerical simulation results using the Verhulst model solved with the Adams-Bashforth-Moulton method, an estimation of coconut harvest yields in North Maluku Province was obtained for the period from 2024 to 2033. Initial values were calculated using the fourth-order Runge-Kutta method and served as the basis for applying the Adams-Bashforth-Moulton method to generate predictor and corrector solutions. The simulation results indicate that from 2024 to 2026, harvest yields increased very slowly, with an average annual growth of approximately 0.003%, followed by a sharp spike in 2027, marking the transition to the rapid growth phase in the Verhulst model. Additionally, a decline in coconut harvest was observed in the early data period, specifically a 1.923% decrease from 2022 to 2023, reflecting notable production fluctuations before the system stabilized near the maximum capacity of approximately 432,600 tons. As a strategic recommendation, local government and stakeholders in the coconut industry in North Maluku Province are advised to integrate these prediction results into the planning of coconut processing infrastructure, such as coconut oil processing plants, to capitalize on the potential production increase expected after the rapid growth phase in 2027. Furthermore, planning related to import-export projections and raw material inventory management strategies should be adjusted to the stability of harvest yields, which are projected to reach a maximum capacity of approximately 432,600 tons by the end of the 2033 period, ensuring optimal supply availability and supporting price stability and the sustainability of coconut production in the region.

In response to the identified trends, specific actions that can be taken by local authorities include investing in early-warning systems for climate anomalies, providing technical training and extension services to farmers on adaptive cultivation practices, and allocating budget for infrastructure that supports post-harvest processing and distribution. Farmers, on the other hand, can respond by adopting diversified cropping systems to reduce risk during periods of yield decline, improving soil and water management practices, and forming cooperatives to strengthen bargaining power in the supply chain.

It is also important to acknowledge that while the Verhulst model provides a useful framework for understanding population-like growth behavior in agricultural production, it is based on simplified assumptions, such as a fixed carrying capacity and homogeneous growth rates, which may not fully capture the complexities of real-world agricultural systems. Similarly, the numerical methods employed—though effective—are limited in their ability to predict long-term outcomes in the presence of unpredictable external variables such as extreme weather events, policy shifts, or global market volatility. As such, future research should aim to incorporate more dynamic and region-specific variables to enhance the robustness of the model and improve the accuracy of long-term forecasting.

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