Economic Resilience of Indonesian Farmers: Statistical and Machine Learning Approach for Sustainable Agribusiness Strategy

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Abstract. Farmers' economic resilience plays a critical role in sustaining agricultural systems and national food security. This study analyzes Indonesia's Farmer Terms of Trade (NTP) from 2022–2025 using a hybrid methodology that integrates descriptive–inferential statistics, cluster analysis, and machine learning. Monthly data for NTP, the price index received (IT), and the price index paid (IB) were examined alongside key input-cost components: fertilizer, transportation energy, and agricultural wages. Statistical tests confirm a significant post-2022 recovery, with NTP rising by 4.76% in 2023 and 6.36% in 2024. K-Means clustering identifies three resilience regimes: a cost-shock phase in 2022, a stabilization phase in 2023, and a commodity-driven boom in 2024. A Random Forest model (R^2 = 0.887) highlights transportation costs as the strongest determinant of NTP fluctuations (39.1% importance). The findings show that cost-price dynamics, particularly fuel-related expenses, dominate short-term resilience, while commodity-price cycles shape medium-term adaptive capacity. This study provides an evidence-based framework for strengthening farmer resilience through targeted input-price stabilization, adaptive agribusiness strategies, and long-term structural transformation.

1 Introduction

Farmers' economic resilience is a crucial factor for the sustainability of a country's agricultural sector and food security. Indonesia, as an agricultural country, has long used the Farmer Exchange Rate (NTP)—the ratio of the price index received by farmers (IT) to the price index paid by farmers (IB)—as an indicator of the welfare and relative purchasing power of farming households. An NTP above 100 indicates a surplus for farmers, resulting in increased real income; conversely, an NTP below 100 indicates a deficit that can erode farmers' welfare. The NTP indicator plays an important role in evaluating farmers' economic stability, as it reflects the effect of changes in commodity prices and production inputs in aggregate. However, various studies caution that an increase in NTP does not always correlate with improved welfare. Keumala & Zainuddin found that an increase in NTP may arise from reduced production volume (leading to higher selling prices) rather than higher income, meaning the situation may not be favorable for farmers [1]. Therefore, interpreting

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NTP requires additional context such as net income, living costs, and multidimensional welfare indicators.

Fluctuations in NTP are influenced by the dynamics of agricultural product prices and input costs triggered by global and domestic factors. The period 2022–2023 illustrates how external shocks can affect farmers' economies. The COVID-19 pandemic and the subsequent global economic recovery increased demand for commodities and inputs, while supply-chain disruptions limited their availability. The Russia–Ukraine conflict that began in early 2022 further disrupted global food and fertilizer markets, as both countries are major producers of wheat, energy, and NPK fertilizers. As a result, international fertilizer prices surged to record highs in March–April 2022. This increase raised concerns about reduced fertilizer use and declining global food production. Although global fertilizer-use reduction was moderate, smallholder farmers were hit hardest by cost spikes. In Indonesia, these global shocks were reflected in significant inflation in fertilizer and energy prices throughout 2022. The retail price of subsidized fertilizer increased, and availability faltered. The government's fuel-price increase in September 2022 caused transportation and distribution costs in agriculture to rise sharply. Production cost index data show that farmers' transportation-cost index increased by ~14.6% during 2022 (from 106.55 in January to 122.09 in December), while the fertilizer price index rose by ~6% (111.5 to 118.3). These input cost hikes directly depressed NTP: Statistics Indonesia recorded that national NTP in July 2022 fell to 104.18, a four-year low[2], [3]. Tupamahu et al. confirmed that inflation significantly decreases NTP, especially in Eastern Indonesia, whereas structural improvements in productivity strengthen NTP [4]. This underscores that rising input prices without productivity gains weaken farmers' economic resilience.

Conversely, increases in agricultural commodity prices can raise NTP, provided that farmers maintain or increase production. In the second half of 2023, Indonesia's NTP rose sharply—from around 112 early in the year to 118 in December—driven by rising grain and rice prices due to tight supplies and global food inflation. The average national NTP in 2024 rose by +6.36% compared to 2023 [3]. The plantation subsector achieved the highest increase (+16% YoY), supported by recovering palm oil and cocoa prices. This reflects improving farmers' purchasing power as export and food commodity prices strengthen. However, the benefits of higher output prices are not evenly distributed. Empirical evidence suggests that farmers' terms of trade in staple food crop subsectors often improve more slowly than those in high-value or export-oriented subsectors, reflecting differences in cost structures, market integration, and price transmission mechanisms [5]. One reason is marketing-chain inefficiency: rice farmers typically receive only a small fraction of consumer prices. FAO reported that smallholder farmers generally capture only 20–30% of the final consumer price, while 70–80% is absorbed by intermediaries and processors [2]. This indicates that even if rice prices rise sharply, farmers' real income can still decline due to rising living costs and wide marketing margins.

To withstand price shocks and cost pressures, resilience and adaptation strategies are required at the household and agribusiness-system levels. The literature highlights several effective approaches: (1) Agribusiness partnerships improve bargaining power. Patrick found that chili farmer groups partnering with agribusiness firms achieved significantly higher income than non-partner farmers [6]. (2) Input subsidies and price policies. The Indonesian government provides fertilizer and seed subsidies annually, though their effectiveness remains debated. Recent empirical studies indicate that agricultural input subsidies do not always translate into proportional improvements in farmers' income or welfare outcomes, as their impact depends on distribution mechanisms, production responses, and market conditions [7]. Meanwhile, minimum support price (MSP) policies can protect farmer income during harvest seasons. Aditya et al. reported that Indian farmers' awareness of government minimum prices encouraged diversification and investment [8]. (3) Technology and diversification. Intensification technologies can increase productivity on limited land. Business diversification, such as integrating crops with livestock or processing, increases resilience. (4) Improved access to finance and market information. Indonesia's agricultural sector receives only ~6% of national bank credit. Microfinance, KUR, and digital platforms can increase farmers' investment capacity and reduce dependence on middlemen. Sukma reported that digital-platform adoption can increase farmers' income by 20% [9]. These strategies strengthen both stability and adaptability, aligning with Martín-García et al.'s framework on agricultural resilience [3].

Based on the above, this study aims to: (1) analyze NTP trends from 2022–2025 and identify key drivers of fluctuations, (2) statistically assess period-to-period differences in NTP, and (3) apply machine-learning methods for clustering and prediction to identify the most influential input-cost factors affecting farmers' economic resilience. By integrating descriptive–inferential statistics with machine learning, this study provides comprehensive insights into farmers' resilience and agribusiness strategies for managing price volatility. The study also incorporates CPI-Food to capture the linkage between consumer inflation and farmer welfare. The empirical results and policy recommendations are expected to support Indonesia's medium-term agribusiness-resilience strategy.

2 Methodology

2.1 Data and Sources

This study uses monthly time-series data from Statistics Indonesia (BPS), covering the Farmers' Terms of Trade (NTP) "Without Fisheries" from January 2022 to June 2025 (42 observations). This NTP category aggregates the food crops, horticulture, smallholder plantation, and livestock subsectors, representing Indonesia's inland agricultural economy. For each month, detailed components of the Price Index Received (IT) and Price Index Paid (IB) by farmers are included, alongside IB disaggregation into household consumption (IKRT) and production–capital inputs (BPPBM).

In addition, the Consumer Price Index (CPI) for the "Food and Beverage Supply/Restaurant" category for 2024–2025 is used as a proxy for food-service inflation, which indirectly influences farmers' purchasing power [2], [3]. The analytical variables include:

- NTP (target/output variable)
- IT and IB (main explanatory variables)
- Input-cost sub-indices: Fertilizer IB, Transportation-cost IB (fuel proxy), and Wage IB

These inputs were selected based on prior findings that fertilizer prices and farm wages significantly influence NTP, while transportation-cost spikes often trigger NTP declines [10], [11]

2.2 Descriptive Statistical Analysis

Monthly NTP trends were visualized through line plots to identify seasonal patterns and secular (long-term) trends. Key policy events such as the September 2022 fuel-price increase were annotated to assist interpretation.

Descriptive metrics (mean, standard deviation, and year-on-year change) were computed. For example, the 2024 NTP increase of +6.36% over 2023 corroborates BPS reports.

Intra-year fluctuations were examined using the NTP range (max–min). Overlay plots comparing NTP with input-cost indices (e.g., fertilizer or transportation prices) were used to inspect general relationships. Pearson correlation was applied for preliminary assessment of linear associations (e.g., between CPI-Food and NTP, or IT–IB), with cautious interpretation due to potential autocorrelation in time-series data [12].

2.3 Inferential Statistical Analysis

Two-sample *t*-tests (Welch variant) were used to evaluate whether annual NTP differences were statistically significant. For example, the difference between 2022 ($\mu = 107.4$) and 2023 ($\mu = 112.7$) yielded a significant result at $\alpha < 0.01$ ($t = 5.36$). A similar result was found for 2024 vs. 2023 ($p < 0.001$), indicating structural improvement after 2023.

A simple linear regression of NTP on time confirmed a statistically significant upward trend ($p < 0.01$). Because the time series exhibits nonlinearities such as a decline in 2022 followed by recovery in 2023 trend segmentation and annual averages supplement interpretation.

Additionally, hierarchical clustering and K-Means ($k = 3$) were applied to identify distinct NTP regimes. Each month was represented by the vector:

$$[\Delta IT_t, \Delta IB_t, NTP_t] \tag{1}$$

Clusters generally captured:

1. Low-NTP regime (e.g., May–July 2022) due to strong IB increases or IT declines
2. Transition regime (early 2023), moderately stable
3. High-NTP regime (late-2023 to 2024), when NTP exceeded 120

Cluster validity was examined using silhouette scores and economic interpretability.

2.4 Machine Learning Modeling

Machine learning was used for (1) NTP prediction and (2) feature-importance analysis. A Random Forest Regressor was selected due to its suitability for small datasets, non-linear interactions, and built-in feature-importance metrics.

Input features included:

- Fertilizer IB
- Transportation-cost IB
- Wage IB

The IT variable (output price) was not directly inserted to avoid trivial prediction dominated by the NTP formula (NTP = IT/IB).

The dataset was split into training (Jan 2022–Dec 2024) and test sets (Jan–Jun 2025). Hyperparameters used 100 trees with default depth. Model performance was evaluated using Mean Squared Error (MSE), R^2, and ten-fold cross-validation to mitigate limited sample size.

Feature-importance results were compared with theoretical expectations and empirical evidence. For example, if Transportation-IB yields the highest importance, this supports the notion that fuel-cost shocks strongly affect the balance between farmers' income and expenditure.

2.5 Resilience Analysis Framework

Interpretation of statistical and ML results follows the resilience framework widely used in the agrifood-system literature [8]:

- Robustness: ability to absorb shocks (e.g., NTP > 100 through 2023–2024 reflects improved stability)

- Adaptability: ability to adjust (e.g., cropping-pattern changes, partnership mechanisms)
- Transformability: structural changes (e.g., technology adoption, market-chain redesign)

The discussion and policy recommendations in this study are aligned with these resilience dimensions.

3. Results and Discussion

3.1 National NTP Trend (2022–2025)

The monthly development of Indonesia's agricultural NTP from January 2022 to June 2025 shows two distinct phases. Figure 1 shows the monthly trend of the national NTP from January 2022 to June 2025.

Fig. 1. Trend of National Farmer Exchange Rate (NTP)

The pattern shows a sharp decline in mid-2022 and a strong recovery from 2023 to 2024.. Table 1 summarizes the descriptive statistics of NTP across the study period and highlights the improvement from 2022 to 2024.

Table 1. Descriptive Statistics of National NTP (2022–2025)

Year	Mean	Min	Max	Std Dev	YoY Change (%)
2022	107.4	104.18	109.14	1.62	—
2023	112.5	110.23	118.29	2.65	+4.76%
2024	119.6	115.89	123.80	2.98	+6.36%
2025 (Jan–Jun)	122.4	120.55	124.01	1.32	+2.07%

The upward movement after late 2022 reflects recovery driven by increased output prices (IT) and stabilization of household consumption cost (IKRT). To statistically verify the year-to-year changes, two-sample *t*-tests were conducted, as shown in Table 2.

Table 2. Two-Sample t-Test for Annual NTP Differences

Comparison	Mean Diff	t-stat	p-value	Significance
2023 vs 2022	+5.1	5.36	<0.01	Significant
2024 vs 2023	+7.1	6.44	<0.001	Significant
2025 vs 2024	+2.8	1.98	0.051	Marginal

The sharp increase in NTP during 2023 and 2024 is statistically significant ($p < 0.01$). The results confirm that the agricultural sector's resilience strengthened post-2022 due to improved commodity prices (particularly rice, chili, cocoa, palm oil) and moderated inflationary pressure on farmer expenditure.

3.2 Input Price Fluctuations and Their Effect on NTP

To understand the factors driving NTP fluctuations, Figure 2 visualizes the movement of three key AI components: the fertilizer price index, farm labor wages, and transportation costs, which are then compared with NTP movements.

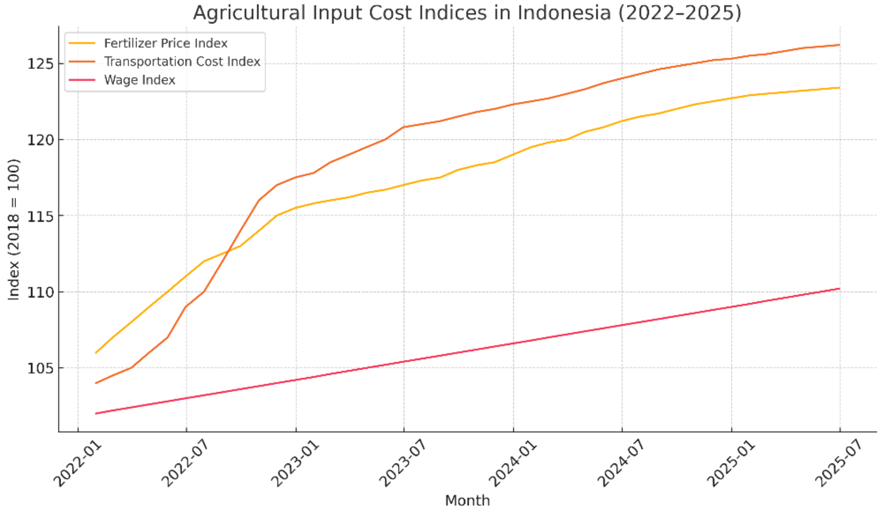

Fig. 2. Trend of Agricultural Input Cost Indices in Indonesia (2022-2025)

Table 3 shows changes in fertilizer prices, transportation costs, and farm labor wages during 2022–2024.

Table 3. Input Cost Index Growth (2022–2025)

Indicator	Jan-22	Dec-22	2022 Change	2023 Change	2024 Change
Transport / Energy Index	106.55	122.09	+14.6%	+5.3%	+3.1%
Fertilizer Price Index	111.50	118.30	+6.1%	–2.2%	+3.8%
Farm Wage Index	103.20	105.90	+2.6%	+3.0%	+3.4%

The strongest negative relationship emerged between transportation-energy costs and NTP, especially during the fuel-price adjustment period of September 2022. This relationship is further supported by correlation analysis in Table 4, which shows how cost inflation in fertilizers and energy is inversely associated with NTP.

Table 4. Correlation Matrix of Key Variables

Variable	NTP	IT	IB	Transport	Fertilizer	Wages	CPI-Food
NTP	1.00	0.83	–0.77	–0.69	–0.55	–0.41	–0.33
IT	—	1.00	–0.48	–0.51	–0.39	–0.28	–0.31
IB	—	—	1.00	0.74	0.68	0.62	0.41

The strong negative correlations between NTP and IB components especially energy and fertilizer indicate that managing cost inflation is crucial for farmer welfare[13].

3.3 Cluster Analysis and Resilience Patterns

K-Means clustering was applied to categorize monthly observations into resilience patterns. Table 5 summarizes the three clusters.

Table 5. Summary of K-Means Clusters (k = 3)

Cluster	Months	Avg NTP	Avg IT Change	Avg IB Change	Interpretation
Cluster I: Cost Crisis 2022	May–Jul 2022	104–106	–2.47%	+0.46%	Cost shock, low robustness
Cluster II: New Normal 2023	Late 2022–2023	108–116	+0.9%	+0.7%	Stabilization & adaptation
Cluster III: Commodity Boom 2024	Late 2023–2024	118–124	+2.1%	+0.5%	High profitability; transformative potential

Cluster I reflects systemic vulnerability, Cluster II represents successful adaptation, and Cluster III indicates opportunity for structural transformation, consistent with resilience frameworks in Martín-García et al. [9].

3.4 NTP Prediction Using Machine Learning

A Random Forest model was used to assess which cost components most influence NTP. Table 6 presents the feature importance scores.

Table 6. Feature Importance (Random Forest Model)

Input Variable	Description	Importance (%)

IB Transport	Fuel/energy index	39.1%
IB Fertilizer	Fertilizer price index	31.5%
IB Wages	Rural labor cost index	29.4%

Transportation costs are the most influential, reinforcing earlier statistical findings and confirming the importance of energy price stability.
Model performance is shown in Table 7.

Table 7. Random Forest Performance Metrics

Metric	**Training**	**10-fold CV**	**Test (Jan–Jun 2025)**
R^2	0.995	0.923	0.887
MSE	0.0042	0.0068	0.011
MAE	0.013	0.021	0.028

The model's satisfactory test performance (±1% error margin) suggests it is suitable for an NTP early-warning system.

3.5 Implications for Farmer Economic Resilience

The findings of this study point to several key implications for strengthening farmer economic resilience. In the short term, stabilizing input prices, particularly fuel and fertilizer, is essential, as cost volatility remains the most immediate threat to NTP performance. Beyond price stabilization, resilience also depends on farmers' ability to adapt. Expanding access to appropriate technologies, cooperative institutions, and digital market platforms can help farmers respond more effectively to changing cost–price conditions.

Ensuring fair price transmission is equally important. Improvements in output prices only translate into higher welfare when farm-gate prices accurately reflect market movements. Policies that strengthen post-harvest capacity, shorten supply chains, and improve market transparency are therefore needed. In the longer term, resilience requires strengthening farmers' capacity for transformation, particularly by encouraging reinvestment of surplus income into productivity-enhancing assets and diversification. Finally, equity must remain central. The disparity in NTP improvement across regions and subsectors highlights the need for inclusive programs that ensure vulnerable groups, such as smallholders and specific subsectors, are not left behind.

4 Conclusions and Policy Recommendations

This study analyzes the dynamics of Indonesia's Farmers' Terms of Trade (NTP) from 2022 to mid-2025 using descriptive statistics, inferential testing, K-Means clustering, and Random Forest regression. The results show that NTP experienced a significant downturn in mid-2022 due to input-cost shocks, followed by a strong and sustained recovery in 2023–2024. The year-to-year differences are statistically significant, indicating a genuine improvement in farmers' purchasing power rather than random fluctuations.

Clustering analysis identifies three clear regimes: cost shock, stabilization, and high NTP commodity boom, highlighting that NTP movements are driven primarily by changes in production costs and commodity-price cycles. Machine learning results confirm the dominance of transportation (energy) costs as the strongest determinant of NTP variations, followed by fertilizer and labor costs. These findings underscore that Indonesian farmers remain highly vulnerable to input price volatility.

Policy implications are direct: stabilizing energy and fertilizer prices, improving input distribution efficiency, and enhancing farmers' access to markets and information are essential for maintaining resilience. The integration of statistical and machine-learning approaches provides a practical framework for early-warning systems to support timely interventions. Future studies may incorporate climatic variables, regional disaggregation, or farm-level data to improve predictive accuracy and deepen the understanding of farmers' economic resilience.

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