International Conference on Sustainable Economics, Management, and Accounting (ICSEMA 2025)
Proceedings
Vol. 01 No.01 Year 2025, Page 3765-3775

FOOD SECURITY THREATS IN INDONESIA: A REVIEW OF SOCIO-ECONOMIC FACTORS

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Abstract

The food crop sub-sector, particularly rice farming in Indonesia, has seen limited progress for nearly three-quarters of a century. Farmers continue to experience hardship due to low incomes from their largely subsistence-level agricultural activities. Data indicates a worrying trend of shrinking agricultural land, with the average land size owned by farmers continuing to decline. Moreover, the farming population is dominated by individuals over the age of 45, signaling that agriculture is increasingly unattractive to the younger generation. Consequently, land conversion from agriculture to non-agricultural use continues unabated. This reality stands in stark contrast to the government's goals as outlined in the second pillar of Asta Cita, which aims to strengthen national defense and promote self-sufficiency through food security. There is a clear gap between these aspirations and the current condition of Indonesia's agricultural sector, where sustainability in food crop production remains a low priority. This study employs Neural Network methods and Agent-Based Modeling simulations to identify the most critical root causes of food insecurity in Indonesia and propose solutions for addressing interregional logistics and food trade flow issues. It also seeks to prioritize problems requiring immediate resolution and predict, through simulation, how many years remain before there are no more land-cultivating farmers in Indonesia. A breakthrough initiative—Borderless Farming Integrated with Corporate Farming—is proposed to overcome logistics and food trade challenges between regions, ultimately aiming to improve farmers' welfare.

Keywords: agent-based model, agricultural land conversion, artificial neural network, borderless farming, farmer age

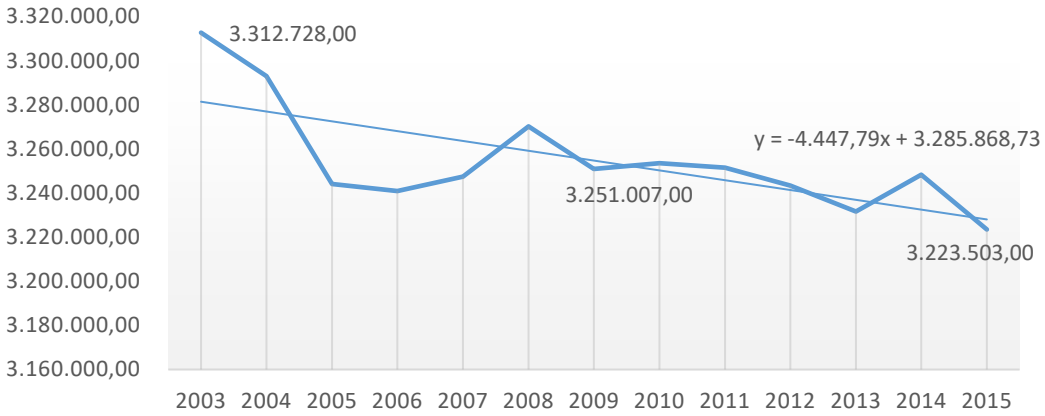
INTRODUCTION

Indonesia is an agrarian country that has experienced continuous agricultural policy development from the time of independence to the present—nearly 75 years. However, the agricultural sector has seen limited significant progress during this period. Farmers still endure difficult living conditions due to their low incomes derived from subsistence farming practices. According to the 2003 Agricultural Census (ST2003, BPS), the number of Farmer Households (RTP) decreased from 31.23 million in ST2003 to 26.13 million in ST2013.

Efforts to improve food security have been made through increased food production and ensuring food availability in every region. Agribusiness development programs have also been implemented through the creation of agribusiness centers or clusters. Initiatives aimed at improving farmers' welfare include extension services, assistance programs, business insurance, grain price protection, and other protective and promotional policies.

Nevertheless, current data presents a concerning reality. The harvested area in Indonesia has been experiencing a sharp annual decline, averaging 211,661 hectares per year. Despite various government programs, data still shows that agricultural land in key production centers, particularly on Java Island, is shrinking significantly. According to BPS data in **Figure 1**, agricultural land on Java Island decreased at an average rate of 4,447 hectares per year. Land that totaled 3,312,712 hectares in 2003 had declined to 3,251,007 hectares in 2009 and further to just 3,223,503 hectares by 2015.

These figures reflect that agriculture is no longer an attractive sector, especially for the younger generation poised to replace today's aging farmers. Agriculture is still often perceived as an informal sector, unreliable for providing a decent standard of living.



Source: BPS

Figure 1. Land Area of Agriculture in Jawa Island (Ha)

The average household income from farming activities in 2013 was only IDR 7.41 million per year (or approximately IDR 617,780 per month), a slight increase from IDR 7.09 million per year in 2004. Low income level has failed to attract young people to become farmers, as shown in **Table 1**. The growth rate of new farmers is only 0.99%, while the retirement rate is 13.81%. The exit rate from farming is 13 times higher than the entry rate, suggesting that without new policies, Indonesia may soon face the disappearance of the farming profession altogether.

Table 1 Age Group of Main Farmer Households in Indonesia (2018)

Description	Age Group of Heads of Farmer Households						
Age Group	< 25	25 - 34	35 - 44	45 - 54	55 - 64	≥65	Amount
Amount	273.839,00	2.947.254,00	6.689.635,00	7.813.407,00	6.134.987,00	3.822.995,00	27.682.117,00
%	0,99%	10,65%	24,17%	28,23%	22,16%	13,81%	100,00%
% Group	35,80%			64,20%			100,00%

Source: SUPAS, BPS

Policy breakthroughs are necessary to ensure the success of the food self-sufficiency agenda outlined in the second Asta Cita pillar. This study bridges the gap between the national food self-sufficiency programs and the current agricultural conditions that hinder their realization. It aims to address food availability logistics issues across regions to support sustainable agriculture.

Based on the background described earlier, the research questions in this study are as follows (1) How do the factors that threaten food security, namely agricultural land area, harvested area, number of farmer households, and age group of farmers, affect the farmers' terms of trade (Nilai Tukar Petani)? (2) How can the priority order of these food security threat factors be determined to identify which problems need to be addressed first? (3) What will the number of farmers in Indonesia look like in the coming years?

This study aims to determine whether the current agricultural land area is beneficial or detrimental to farmers' terms of trade. It also seeks to identify the most critical issues in Indonesia's food security program and propose solutions to overcome these problems, particularly those related to interregional food logistics and trade flows, so that the priority order of issues can be established

and targeted interventions can be designed to improve farmers' incomes. Additionally, the study will forecast the future of farming as a profession in Indonesia using simulation models. It will also offer solutions to food security threats as part of a mitigation strategy to maintain the continuity of the food self-sufficiency agenda outlined in the second pillar of Asta Cita.

LITERATURE REVIEW

Chenery's Pattern of Development Theory (1960) explains economic development as a set of interconnected changes in economic structure required for transitioning from an agricultural economy to an industrial economy in pursuit of sustainable growth, alongside capital accumulation, both human and physical. The core idea is a sectoral shift from agriculture to industry. Per capita income is expected to rise in line with the industrial sector's growth, which is driven by capital accumulation and human resources. Chenery's model emphasizes the need for structural transformation in underdeveloped economies to pave the way for new industrial penetration and modern economic structures capable of achieving industrialized-nation status (Chenery, 1960). It closely resembles Lewis's model but argues that while investment and savings are necessary, they alone are not sufficient to drive the desired growth rate. Although Chenery's approach provides valuable insight into structural transformation, it also has limitations. One key criticism is that it underemphasizes critical assessments of goods and their impact. Despite this, the model is helpful in analyzing economic growth across countries with varying economic systems and can support mutual understanding in economic relationships. Therefore, this model remains relevant in guiding the development efforts of emerging economies in a globalized context (Greider, 1997).

Empirical Gap

Based on a sample of approximately 100 articles from reputable international journals indexed by Scopus, it is evident that research topics on food security are dominated by themes such as climate change, global food security, household food security, COVID-19, threats, human health, and others (as shown in Appendix 1). From these themes, a topic mapping was constructed, which is illustrated in Figure 2.

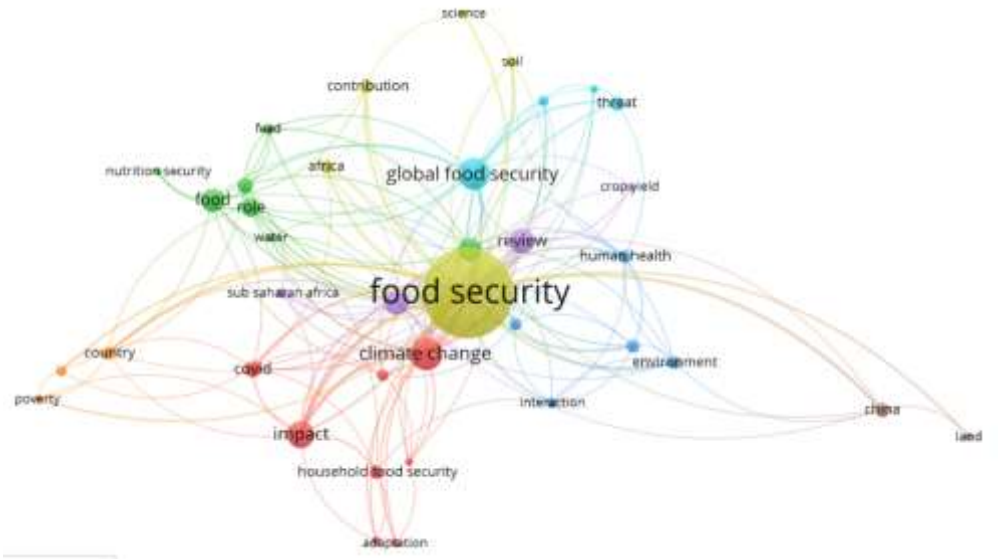


Figure 2. Mapping for Food Security in Scopus Indexes of International Journal

This study aims to explore several hidden threats to Indonesia's food security and offer potential solutions to overcome logistical challenges in support of sustainable agriculture. Threats in the agricultural sector such as land shrinkage, decreasing harvested area, aging farmer demographics, declining number of farmer households, and unfavorable terms of trade are

identified as key risks to be addressed in the national food security agenda. These aspects remain underexplored in Scopus-indexed international journal articles.

The topic of this study also addresses the gap between the Indonesian government's food security plans and the actual field conditions, such as shrinking agricultural land and declining productivity, combined with the aging farmer population, decreasing farmer household numbers, and unfair terms of trade. While the second pillar of Asta Cita has been broken down into several Priority Programs (PP), Priority Activities (KP), and the development of Food Production Center Areas (KSPP) across various provinces, these initiatives must be critically compared to the existing conditions. These existing challenges should be acknowledged as significant risks and incorporated into the national development risk management framework for mitigation and treatment.

Analytical Gap

A review of selected articles from Scopus-indexed international journals shows that most research on food security tends to rely on a single analytical method, such as regression, causality testing, impact evaluation, or other individual techniques. In contrast, this study employs a combination of multiple analytical methods, each supporting the application of the next. First, Artificial Neural Networks (ANN) will be used to identify the root causes of these conditions. Lastly, the main problems identified will be analyzed using the Agent-Based Model (ABM) to predict whether these issues will result in long-term threats to food security in Indonesia. Several critical risks that threaten the food self-sufficiency priority program under the second pillar of Asta Cita must be considered inherent risks and urgently subjected to risk control measures. These include,

(a) Shrinking Agricultural Land Over the Years. The conversion of agricultural land into non-agricultural uses is a global issue that significantly impacts food security. Lambin and Meyfroidt (2011) identified urbanization and industrial expansion as major drivers of land conversion, which threatens food production in many countries. In Indonesia, this phenomenon is evident in the declining area of rice fields due to infrastructure and housing development.

(b) Decreasing Harvested Area Over the Years. Global climate change has had a significant impact on Indonesia's agricultural sector, particularly by reducing the harvested area and overall productivity. Rising average temperatures, shifts in rainfall patterns, and an increase in extreme weather events, such as floods and droughts, directly affect the agricultural production cycle. A study by Nelson et al. (2009) projects that without effective mitigation efforts, climate change could reduce crop yields by up to 25% in developing countries, including Indonesia. Unpredictable weather patterns create uncertainty for farmers in determining optimal planting times, which in turn disrupts planting and harvesting cycles.

(c) Low Land Productivity in Indonesia. Low agricultural land productivity in many developing countries is often the result of reliance on traditional farming practices and the slow adoption of modern technology. Fuglie and Rada (2013) argue that countries slow to embrace agricultural innovations tend to experience stagnation in productivity. In many developing nations, farmers still depend on conventional methods with limited inputs, which leads to low yields per hectare.

(d) Lack of Interest Among the Younger Generation to Become Farmers. The aging of the farming population and the lack of regeneration among younger agricultural workers is a global issue. Leavy and Hossain (2014) found that in many developing countries, younger generations are reluctant to enter the agricultural sector due to negative perceptions of farming as a profession, lower income prospects, and limited access to land and capital. In Indonesia, data shows that the majority of farmers are aged over 45, while interest from the youth in taking up farming continues to decline. If this trend persists, Indonesia is at risk of facing a labor crisis in the agricultural sector, which could seriously endanger national food security.

RESEARCH METHODS

This study employs the Artificial Neural Network (ANN) method, specifically, the multi-layer perceptron (MLP) architecture, also known as feed-forward neural network (FFNN). This method is chosen due to its flexibility in handling various types of data and analysis models such as regression, nonlinear regression, discriminant analysis, and data reduction (Subanar, 2005; Sarle, 1994). The analysis is conducted using the backpropagation training method with the Levenberg–Marquardt optimization algorithm. Input data is transformed into a normal distribution using a binary sigmoid activation function (via mapminmax) as a prerequisite for backpropagation. The network architecture consists of one hidden layer and one output layer, with the optimal number of neurons determined by minimizing the mean square error (MSE) and sum square error (SSE) during training.

Neural Network Architecture use the input layer includes agricultural land area, harvested area, number of farmer households, farmer age group. The output layer represents farmers' terms of trade (NTP). The optimal number of neurons in the hidden layer is determined by observing the training performance and the convergence of the error to the minimum value. The model estimation used in this study is as follows:

$$\hat{e}: f_{\bullet}^{\circ}\left[w_{\bullet}^{\circ} f^{h}\left\{\left(w_{t}^{h}.x_{t}+b_{t}^{h}\right)+\left(w_{s}^{h}.x_{s}+b_{s}^{h}\right)\right\}+b_{\bullet}^{\circ}\right] \quad (1)$$

where,

$\hat{e}$: output variable (farmers' terms of trade)

$f_{\bullet}^{o}$: activation function of the output layer

$w_{\bullet}^{o}$: weights from hidden layer neurons to output neuron

x_{t} : input variables (e.g., land area, harvested area, age, household amount)

w_{t}^{h} : weights from input to hidden layer

$\mathrm{f_t^h}$: activation function in the hidden layer

b_{t}^{h} : bias from neuron of input variable e.g. farmer age and farmer household in the hidden layer

f^{h} : neuron activation function in the hidden layer

$b_{\bullet}^{o}$: bias for output layer neuron

The goodness-of-fit metrics used include MSE and SSE, aiming for the lowest possible values. Since the weight values between input and hidden neurons become increasingly complex, they cannot be interpreted solely through post-analysis of the training phase. Therefore, this study uses the Garson Algorithm (Olden & Jackson, 2002) to partition and calculate the relative contribution of each input to the output. The result of the Garson Algorithm helps identify the priority order of issues from most urgent to least, based on their impact on the farmers' terms of trade, specifically from the input variables (Garson, 1991).

Agent-Based Model (ABM)

The Agent-Based Model (ABM) is a simulation approach that involves the creation of autonomous agents with specific rules and behaviors to explore complex systems. ABM is grounded in complexity theory, which posits that complex systems exhibit emergent behavior resulting from simple local interactions between individual elements. Numerous studies have utilized ABM to investigate various topics, including the spread of infectious diseases, economic market dynamics, social network analysis, and environmental sustainability. According to Tesfatsion (2006), ABM

analyzes economic processes as dynamic systems involving heterogeneous agents who interact using increasingly powerful computational tools. Pyka and Fagiolo (2007) emphasize that repeated interactions among agents in ABM produce constantly evolving microeconomic patterns. When aggregated, these interactions generate macroeconomic dynamics that become the focus of analysis. Recent contributions by leading experts in agent-based economics and computational economics demonstrate ABM's relevance across a wide range of economic issues. For example, Poledna et al. (2024) studied the macroeconomic implications of hypothetical migration scenarios and their labor market effects on various demographic groups in Austria. The study concluded that Austria's labor market and economy could adapt to such immigration waves, as increased aggregate consumption and investment positively influenced GDP. However, higher unemployment rates were observed among both natives and previous immigrants.

This study simulates Indonesia's agricultural conditions using data from SUPAS 2018 to forecast future scenarios, specifically, whether Indonesia will still have land-cultivating farmers in the coming years. The ABM simulation aims to determine how many years remain before the farming profession disappears from Indonesia's agricultural system and how this outcome would affect the national food security program outlined in the second pillar of Asta Cita and the Food Self-Sufficiency Priority Program set for the coming years.

RESULTS AND DISCUSSION

Artificial Neural Network Analysis

The estimation of the magnitude of local government tax effort was carried out using a feed-forward neural network with the backpropagation method. The network was trained using the Levenberg–Marquardt algorithm. The analysis based on this training method employed one hidden layer and one output layer. Prior to the analysis, the input data were structured as panel data. The input variables consisted of agricultural land area, harvested area, farmers' terms of trade (NTP), number of farmer households, age group of farmer households. The target variable was the agricultural sector GRDP per capita. The data were then transformed into a normal distribution following a binary sigmoid function. The dataset was split into two sets: 73.5% for training and 26.5% for testing, as presented in Table 2.

Table 2. Data for Training and Validating

Case Processing Summary			
		N	Percent
Sample	Training	83	73.5%
	Testing	30	26.5%
Valid		113	100.0%
Excluded		0	
Total		113	

Table 3. Goodnes of Fit

Training	Sum of Squares Error	16.433
	Relative Error	.401
	Stopping Rule Used	1 consecutive step(s) with no decrease in error[a]
	Training Time	0:00:00,03
Testing	Sum of Squares Error	9.270
	Relative Error	.471
Dependent Variable: pdrb_perkapita_pertanian		
a. Error computations are based on the testing sample.		

The analysis of the relationship between input variables and the target variable shows that the age group of farmer households is the most critical factor. This finding suggests the need for government intervention to make the agricultural sector more appealing to younger generations as part of a regeneration effort. The second most important variable is land area, which continues to shrink over time, often due to inheritance, which divides farmland into increasingly smaller plots. The third in importance are harvested area and farmers' terms of trade, while the number of farmer households has relatively less impact compared to the age group and land area variables. This prioritization is shown in **Table 3, Table 4** and **Figures 3**.

Table 4. Independent Variable Importance

	Importance	Normalized Importance
luaslahan	.260	78.4%
luaspanen	.242	73.0%
ntp	.084	25.3%
rt_petani	.082	24.6%
kelompok_umur_rt	.332	100.0%

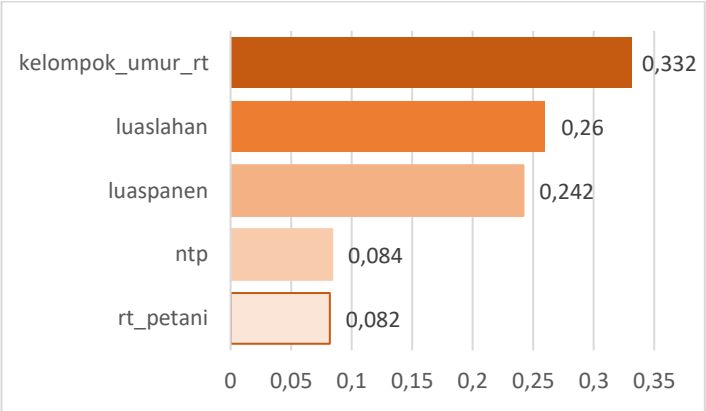


Figure 3. Relative Importance

Agent-Based Model Simulation Analysis

This simulation employs an Agent-Based Modeling (ABM) approach to analyze the dynamics of Indonesia's farming population based on data from the Agricultural Census conducted by BPS. The model focuses on the interaction between two key variables: the rate of farmer addition and the rate of farmer reduction, which together influence the total number of farmers over time. The simulation structure is built using a stock-and-flow diagram, where the number of farmers is modeled as a central stock affected by inflows (new farmer entries) and outflows (farmers exiting the profession). The simulation results show a significant imbalance: the rate of farmer reduction (0.268) greatly exceeds the rate of farmer addition (0.0017). This discrepancy indicates that the farming profession is in a state of continuous decline (**Figure 4**).

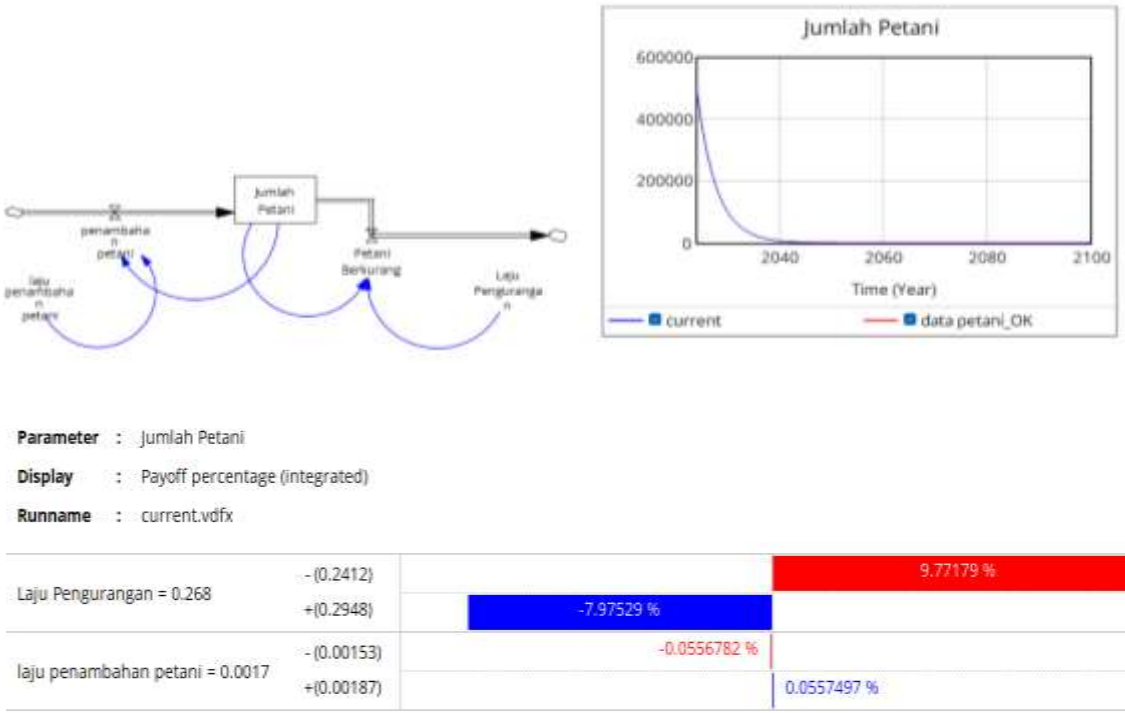


Figure 4. Result of Agent Based Model

The projection graph illustrates that the number of farmers in Indonesia will drop sharply, nearing zero around the year 2040. This projection implies that, within the next 40 years, the agricultural sector in Indonesia may face a severe crisis due to the disappearance of farming as a viable profession. This trend poses a direct threat to national food security and demands urgent policy intervention. Regeneration of farmers must become a strategic priority, particularly by encouraging youth participation through improved access to land, financing, training, and modern technology.

Prediction Simulation with Agent Based Model

To validate the long-term projection results, a simulation was conducted using the Agent-Based Model (ABM) framework. The visual simulation presented in the slide illustrates two key scenarios. The left panel represents the current condition, where the farming population is distributed across various age groups, from under 25 years old to over 70. This distribution reflects the present demographic composition of Indonesian farmers, which, while still diverse, is predominantly composed of older individuals. In contrast, the right panel displays the projected future condition. In this scenario, almost all farmers have disappeared, leaving only a small number of farmers within the 60–65 age group. This stark visualization highlights the critical impact of declining regeneration in the agricultural sector (Figure 5).

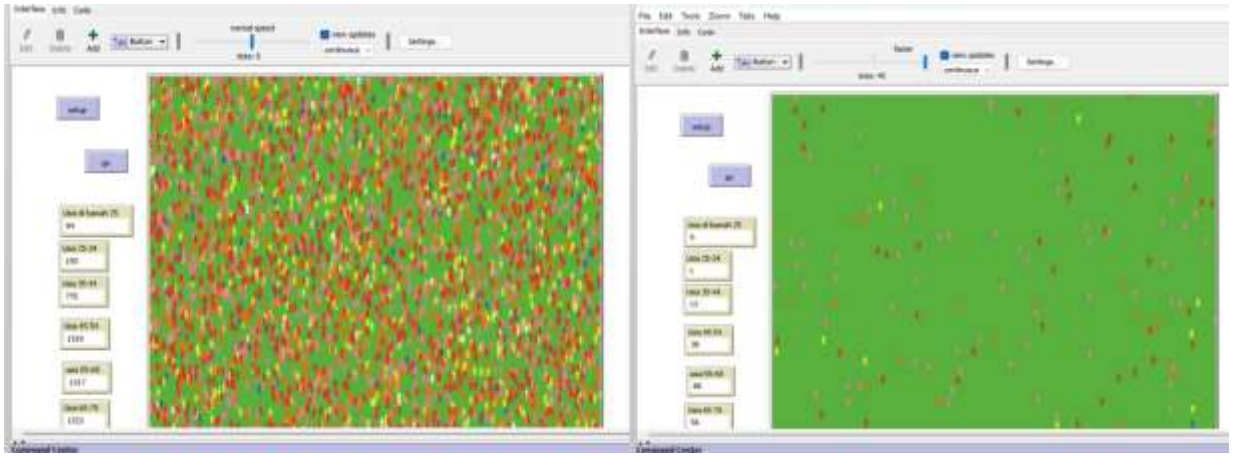


Figure 5. Agent-Based Model Simulation

The simulation confirms that younger generations are not entering the farming profession, while existing farmers are aging out of the workforce. This leads to an inevitable collapse in the number of active farmers if current trends persist. The simulation strongly reinforces previous findings that within approximately 40 years, Indonesia could face a near-total disappearance of its farming workforce. This situation poses a structural threat to the sustainability of the agricultural sector and, more broadly, to national food security. Without significant and targeted policy interventions to attract younger generations into agriculture and ensure generational continuity, the risks identified by this simulation could become a harsh reality.

CONCLUSION

Indonesia's agricultural sector is currently facing serious challenges that could undermine the long-term sustainability of national food security. Based on agricultural census data and other socio-economic indicators, it is evident that the farming population is largely composed of individuals aged 45 and above, while farmer regeneration remains critically low. Agricultural land continues to shrink significantly, land productivity remains low, and the farmers' terms of trade are not yet sufficient to provide a decent standard of living.

The Artificial Neural Network (ANN) analysis revealed that the age group of farmer households is the most influential factor affecting the performance of the agricultural sector, followed by land area. These findings indicate that without effective policies on farmer regeneration and land consolidation, the agricultural sector will continue to lose its competitiveness and vitality.

The Agent-Based Model (ABM) simulation reinforces this concern. The simulation results show that the rate of farmer attrition significantly exceeds the rate of new entrants, meaning that within the next 40 years, farming as a profession in Indonesia could face near extinction without policy intervention. In the long-term scenario, only a small number of elderly farmers (aged 60–65) remain, with no younger farmers entering the sector. This reflects a real and pressing structural regeneration crisis. The simulation confirming that this critical condition persists across different scenarios. It clearly indicates that national food security is not only threatened by external factors such as climate change, but also by an internal crisis, the disappearance of farmers themselves.

Therefore, comprehensive and long-term strategic policy interventions are urgently needed, including giving incentives and support to attract younger generations into agriculture, agricultural modernization and digitalization, and ensuring the welfare and dignity of farmers so that the profession is viewed as viable and promising once again.

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