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A Solution Management in Handling Economic Inequality Among Agrarian Communities

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Abstract: Agriculture has been an inherent part of human civilization for centuries. Therefore, this study aims to analyze the relationship between agricultural production and agricultural community income. The pattern of their relationship followed the dynamics of the Lotka-Volterra model. Two of the six critical phenomena that might occur: first, if the farmer's crop were abundant, the farmers' income would increase rapidly; second, if the farmers' yields decreased, the farmer's income would automatically decrease. Low and unstable farmer income could lead to poor productivity and low economic growth. Thus, monitoring and early warning were essential to effectively prevent possible negative impacts on agricultural product production, consumption, and changes in market prices. Sustainable agricultural systems included maintenance or enhancement of environmental natural resources, food supply, and social welfare. In brief, good agricultural management could maintain the balance of the ecosystem, contribute to the economy continuously, and increase agrarian communities' economic resilience.
Keywords: *agrarian community; ecosystem; harvest cycle; income; Lotka-Volterra.*

INTRODUCTION

Agriculture began approximately 10,000 years ago BC (Gupta, 2004) when humans started domesticating animals and plants to produce foods (Diamond, 2002). Since then, agriculture has been undergoing modification and adaptation in various parts of the world. According to the Food and Agriculture Organization (FAO), the global production of rice has reached 500 million tons, with world rice consumption increasing by 1.1% compared to that in 2017 (Bernaola et al., 2018). Rice production plays an important role in the economy of Asian and African countries (Fahad et al., 2021). In Iran, rice is the second biggest agricultural crop after wheat (Karizaki, 2016). The world is very dependent on sustainable rice production to maintain food security and eradicate poverty (Roy & Chan, 2015).

Since 1970, agricultural production trends show that fish harvest, bioenergy production, and raw material harvest have increased. The production value of crops ($2.6 trillion in 2016) has roughly tripled since 1970. Raw wood harvesting has also increased by 45%, reaching around 4 billion cubic meters in 2017 and enabling the forestry industry to provide 13.2 million jobs. Currently, land degradation has reduced the productivity of the global land area by 23%. On the other hand, the loss of coastal habitat, which increases flood and hurricane risks, impacts the lives and properties of approximately 300 million people living in coastal areas (IPBES, 2019).

Agriculture has become the main livelihood of people in most developing countries and affected their rural economies (Braun & Kennedy, 1994). However, this sector is facing several serious climate changes (such as drought, heavy rainfall, and flood); hence the people who depend on this sector are more vulnerable than those in other sectors (Akudugu et al., 2012). The increasingly dense population growth is also one of many issues that affect this sector because growing populations impact crop production, especially the availability and quality of land (Willy et al., 2019). Land-use change has become one of the most relevant driving forces of environmental degradation worldwide (IPBES, 2019).

Over the last few decades, farmers in low to middle-income countries have increased the use of pesticides. This activity poses a risk of being exposed to genotoxic chemicals that could lead to health problems in humans (Cuenca et al., 2019), such as asthma, diabetes mellitus, cancer, Parkinson's, Alzheimer's, and reproductive disorders (Kim et al., 2017).

A sustainable agricultural system has become a primary focus to ensure the survival and well-being of people worldwide. This system is one of many complex subjects that involve a wide range of factors in the fields of economy, social, and environment (Talukder et al., 2020). However, there has not been a single solution to overcome all the problems emerging in all countries. Therefore, each country must find its method for creating a sustainable agricultural system under its respective economic, ecological, and social conditions (Niemmanee et al., 2015).

In Asia and sub-Saharan Africa, smallholder farmers' income is very low and can be identified by sharp fluctuations (Fanzo, 2017). Agricultural production requires a long period to complete. Thus, the inadequate distribution channel of agricultural products is a serious threat. An inadequate distribution channel can lead to income uncertainty (Gilbert & Morgan, 2010). Smallholder farmers living in rural communities in low-income countries account for more than 70% of the world's total population who are poor and food insecure (FAO et al., 2013).

The Indonesian Ministry of Agriculture continues to aim at community welfare improvement through various programs of massive mechanization and infrastructure development. They aim to reduce the poverty rate and income inequality. On a nationwide scale, the number of people living in poverty in 2019 decreased to about 9.41%. This decrease is significantly better than the rate from March to September 2018, which reached 9.82% and 9.66% (KPRI, 2019).

Indonesia possesses an agricultural land area of 7,105,145 Ha in 2018 and 7,463,948 Ha in 2019 (KPRI, 2020). Based on the data from the Indonesian Statistics Agency (*Badan Pusat Statistik* or BPS), of the 17 main employment sectors, the agriculture, forestry, and fisheries sectors ranked first with 28.79% (2018) (BPS, 2018) and 27.33% (2019) (BPS, 2019) employment rates respectively of the total working-age population. Meanwhile, rice production in 2018 reached 59.20 million tons, and in 2019, it decreased by 4.6 million tons. Thus the total rice production was only 54.60 million tons (BPS, 2021).

Changes in human behavior (driven by population growth, economic development, technological advances, and agricultural land expansion) create newer and more intensive interactions between humans, livestock, and wildlife. These changes have been identified as some of the factors that instigate the spread of infectious diseases with serious impacts on livelihoods and human health (Jones et al., 2013). Currently, several infectious diseases (for example, Covid-19, MERS, SARS, and avian influenza) have a high possibility of spreading among many countries in the world because those countries are interconnected through trade and airline traffic (Morand, 2018).

Therefore, a sustainable agricultural system can minimize the emergence risk of new types of infectious diseases. This system is also needed to meet the increasing global food needs while protecting human health and preserving biodiversity and the environment (Jones et al., 2013). Thus, the research question is how to manage the agricultural sector without destroying nature while still producing sustainable economic resilience.

Mathematics has developed rapidly, especially in the field of mathematical modeling. One of the most commonly known mathematical models is Lotka-Volterra (L-V) model. The L-V model is also known as the predator-prey model. This model contains a pair of non-linear differential equations and is usually used to describe the dynamics between two interacting species. The first species is called prey, and the second one is called a predator (Bacaer, 2011; Lotka, 1910). Apart from biology and epidemiology, the L-V model has long been known in economic theory (Gandolfo, 2008). At present, this model has been widely used to analyze various economic, energy, computer engineering, and industrial phenomena (Kreng et al., 2012; Marinakis et al., 2020; Tsai et al., 2016; Zhang, 2012). Therefore, this study adopts the L-V model to examine the interaction dynamics between agricultural production and the income of agricultural communities. This research is also equipped with empirical data or facts obtained from direct observations in the field. Universally, healthy and sustainable agriculture plays a significant role in the economies of many countries. Sustainability is implemented in the agricultural sector to overcome poverty alleviations, food security, and stable income (Al-Shayaa et al., 2021).

The Indonesian Ministry of Agriculture has continued to improve community welfare through various programs for massive mechanization and infrastructure development. The success of agricultural sector development has a significant role, especially in reducing poverty and income inequality (KPRI, 2019).

Demands for food will increase by 60-70% over the next 40 years. In the meantime, the environment might experience drought or high rainfall due to extreme weather, which eventually brings an adverse impact on food production (Valin et al., 2014). Agriculture is the largest user (about 85% of world production) of pesticides which are chemically used to control various pests (Kim et al., 2017). However, exposure to the pesticide can be harmful to human health and other organisms' health (Sarwar, 2015).

Global warming impacts are significantly diverse and affecting the entire living organisms that inhabit this planet, especially human life. One of the direct impacts of global warming is population migration due to extreme weather (such as hurricanes, droughts, and floods), disease transmission, changes in ecosystems, and food production (Tanure et al., 2020). Therefore, this migration could also cause income instability (Atozou & Lawin, 2016).

The income instability of smallholder farmers in developing countries, which is caused by agricultural price fluctuation, has been a challenge for both the farmers and agricultural policymakers for many years. This income instability carries serious risks for farmers, consumers, and other business actors (Abokyi et al., 2020).

The fluctuation of agricultural commodity prices adversely affects a country's Gross Domestic Product (GDP). Price predictions might help policymakers create regulations that can minimize and manage the risk of price fluctuation (Sabu & Kumar, 2020). In various countries, there has been significant evidence suggesting that the risks of agricultural prices and crops, double cropping, the importance of crops, agricultural income, rent, and literacy are crucial determining factors of agricultural sustainability (Haile, Brockhaus, et al., 2016; Haile, Kalkuhl, et al., 2016; Tabe-Ojong et al., 2020).

Sustainable agricultural systems involve maintaining or enhancing environmental natural resources and meeting food needs and social welfare. If farmers increase their utility functions appropriately, they will contribute to achieving economic goals while preserving the environment (Amini et al., 2020).

The Lotka-Volterra (L-V) model is also known as the predator-prey model. This model contains a pair of non-linear differential equations usually used to describe the dynamics between two interacting species. The first species is the called prey, and the second one is called the predator (Bacaer, 2011; Lotka, 1910). The prey population is usually assumed to have an unlimited food supply and reproduce exponentially, whereas the predatory population is completely dependent on the prey population. If the prey population goes extinct, the predator population will also be extinct. The L-V model has a periodic solution (Gandolfo, 2008) in the form of a cycle. Both populations will not become extinct if they are under a sustainable balance. Therefore, the L-V model can be applied to examine the dynamics of the interaction between agricultural production (prey) and agricultural communities' income (the agrarian communities as predators).

METHODS

This paper offers one way of managing agriculture without destroying nature and also producing sustainable economic resilience, especially among agrarian communities. The approach we use is a mathematical method by adopting the Lotka-Volterra model (L-V). In addition, to support the results of the analysis of the L-V model approach, we also present empirical data. The data are agricultural products from four types of commodities in Waode Kalowo Village, Bonegunu District, North Buton Regency, Southeast Sulawesi.

Furthermore, the process of adopting the L-V model to analyze the dynamics of the interaction between agricultural production (prey) and agricultural communities' income (the agrarian communities as predators) is as follows.

The Lotka-Volterra (L-V) model, known as the predator-prey model, is an equation that has two differential equations with two variables used to describe the dynamics between two interacting species. The first species is the prey and the second one is the predator. The populations change through time (Brauer & Castillo-Chavez, 2012).

By adopting the L-V model, a differential equation illustrating the dynamics of the crop yield and farmers' income was generated:

$$\frac{dx}{dt} = \alpha x - \beta xy$$
$$\frac{dy}{dt} = \delta xy - \gamma y, \qquad (1)$$

where variable x is the total crop that farmer can harvest (prey); variable y is the total farmers' income of farmers from the crop yield (predators); operator $\frac{dx}{dt}$ and $\frac{dy}{dt}$ represent the growth rates of the two variables to the time. The symbol αx is the rate of change in the crops that can be harvested. The symbol βxy is the rate of harvest by farmers; δxy is the rate of income or profit of the farmer obtained from the crop yields, and γy is the level of losses experienced by farmers such as lack of crop yields, low market price, or crop failure (caused by floods or extreme weather such as drought or high rainfall). Every parameter α, β, δ, and γ are positive real parameters.

The Lotka-Volterra (LV) model was applied based on the simplifying assumptions (a-e) and contained only two variables. Variable x shows the total crop that could be harvested by farmers (prey), and variable y shows farmers' total income from the crop (predators). Therefore, this mathematical model could not be applied in analyzing problems that contained more than two variables with more complex assumptions.

RESULTS AND DISCUSSION

Agriculture has become the main livelihood of people in most developing countries and affected their rural economies. However, they are more vulnerable since they have to face serious climate issues such as drought, heavy rainfall, and flood. Furthermore, the process takes a long time, starting with land clearing, planting, maintaining (fertilizing and weeding), and harvesting. Then, the yield is processed (e.g., drying) and sold to the market.

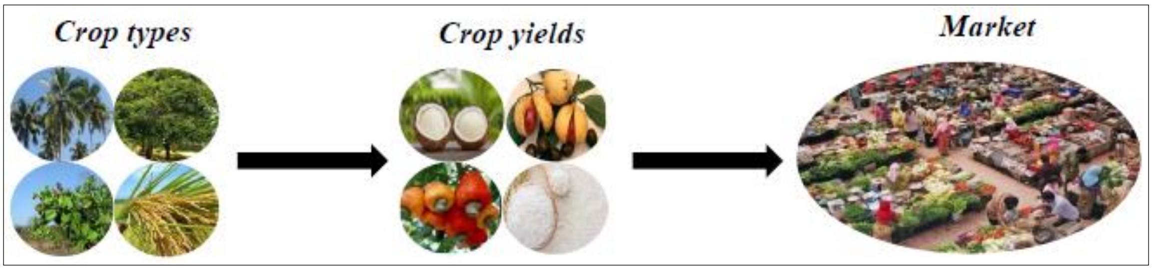

Figure 1. The flow chart of yield processing

Lotka-Volterra (L-V) model in equitation (1) has several simplifying assumptions related to the environmental conditions and its evolution to crop yield and farmers income:

a. The crops have an abundant food supply throughout the year;
b. Farmers' income depends entirely on the total crop yields;
c. Environmental conditions (climate, rainfall, drought, etc.) affect crop fertility;
d. The mean change in the two variables is proportional to their size;
e. Farmers will keep harvesting when the crops are harvest-ready.

Based on those simplifying assumptions, there is a change (from crop yield to income) when farmer harvest their crops. This change includes the productive plants; therefore, $\delta \leq \beta$). Given the equation solutions $\frac{dx}{dt} = 0$ and $\frac{dy}{dt} = 0$, the equilibrium points (1) are:

- Equilibrium point $E_0(x, y) = (0{,}0)$: Farmers do not gain income since there is no crop yield (prey)
- Equilibrium point $E_0(x, y) = (0{,}0)$: Crop yield and farmers' incomes are available (predator)

The analysis will only cover the equilibrium point, which has more than two variables (non-zero number); point $E_1(x, y) = (\gamma/\delta, \alpha/\beta)$. Therefore, the interaction between two variables can be seen.

The eigenvalues were applied to analyze the differential equitation between the crop yield and farmers' income. The eigenvalue for E_1 is $\lambda_1 = i\sqrt{\alpha\gamma}$ and $\lambda_2 = -i\sqrt{\alpha\gamma}$. As the eigenvalues are both purely imaginary and conjugate to each other, the equilibrium point is the center (Wiggins, 2000). As a result, the periodic solution of equation (1) is a closed orbit that rotates anticlockwise surrounding the equilibrium point with frequency $\omega = \sqrt{\lambda_1 \lambda_2}$ and period $T = 2\pi/\omega$. By using Maple application, we show numerical illustrations of the dynamics of crop yields and farmers' income as follows.

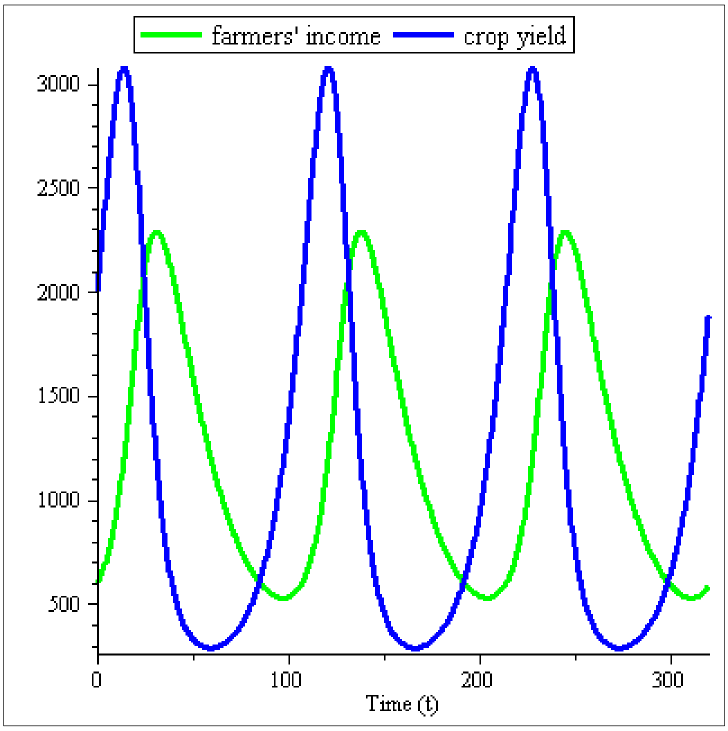

Figure 2. Numerical illustrations of the dynamics of crop yields and farmers' income measured based on time with the initial value $(x_0, y_0) = (2000, 600)$ unit $\alpha = 0.1$ unit, $\beta = 0.00008333$ unit, $\delta = 0.000034$ unit, and $\gamma = 0.04$ unit.

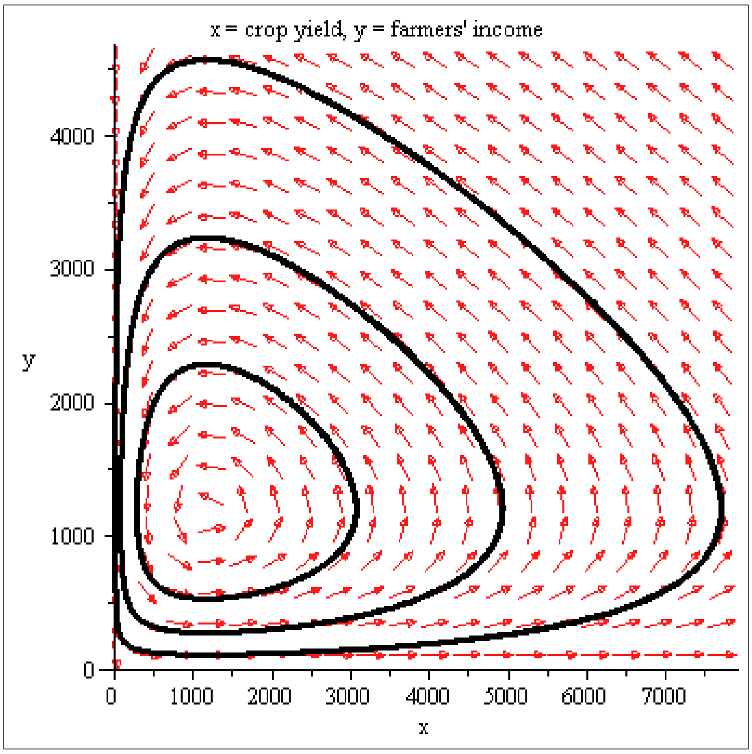

Figure 3. Illustration of phase portrait between crop yields and farmers' income with the initial value $(x_0, y_0) = (2000, 600)$ unit, $\alpha = 0.1$ unit, $\beta = 0.00008333$ unit, $\delta = 0.000034$ unit, $\gamma = 0.04$ unit, and the equilibrium point $E_1 = (1200.048, 1176.47)$.

Figure 2 shows if the crop yield is abundant (stable market price) (αx), the farmers' income will increase (δxy). Conversely, if the crop yield decreases (stable market price) (αx), so is the income. Depending on the environmental condition, the crop will begin the cycle when the harvest season has ended. This is a continuous cycle as long as the crops are supplied with enough food. This phenomenon will form a circular cycle (closed orbit), as presented in Figure 3.

The Lotka-Volterra (L-V) model has been applied in mathematical biology. Mathematician Vito Volterra studied the interactions between various animal species in nature (Lotka, 1920). One of the models Volterra introduced was the pre-predator case. Furthermore, this model was also applied in economic, initiated by Giuseppe Palomba, an Italian economist, in 1939. In 1965, Richard Goodwin brought the LV model into economics to test cyclical problems (growth cycle) (Gandolfo, 2008).

Despite the number of crop yields, the farmers also depend on the market price. The unstable and low income will imply poor productivity and low economic growth (Severini et al., 2016). By considering the market price (high, stable, and low), six phenomena may occur.

> *High market price. First: if the crop yield is abundant, the farmers' income is increasing rapidly. Second: if the crop fields are low due to bad weather such as drought and floods, the farmers' income tends to stable. Stable market price. Third: if the crop yield is abundant, the farmers' income is increasing rapidly. Fourth: if the crop fields are low, the farmers' income will also decrease. Low market price. Fifth: if the crop yield is abundant, the farmers' income tends to stable. Sixth: if the crop yield is low, the farmers' income will also decrease significantly.*

Climate change, biodiversity loss, land-use conversion, mobility, human migration, agricultural land expansion, and biological invasion have sharply declined environmental quality (Daily & Ehrlich, 1996). There is a close relationship between increased human populations and the food supply, which is the basic human need (Gibbs et al., 2010). When the human population continues to increase, the food supply will also increase. Therefore, the agricultural land is expanded through deforestation. Thus, it harms the ecosystem balance. For example, this will drive many wild animals and plants towards extinction (Hurst, 2018).

Research conducted by (Brown, 2004; Cutler et al., 2010; Daszak et al., 2000; Dorny et al., 2009; Epstein et al., 2006; Gould & Higgs, 2009; Gummow, 2010; McMichael, 2004; Newell et al., 2010) shows that there is a close relationship between modern agriculture with the emergences infectious diseases originating from wildlife. The agricultural land expansion disrupted the ecosystem balance and made humans and livestock closer to wildlife and vectors. This frequent interaction opens opportunities for transmitting previously unknown pathogens (e.g., viruses of wild origin) into livestock and the human body. Thus, it will create a new cycle transmission. The environmental changes include habitat fragmentation, deforestation, and vegetation replacement. It eventually disrupts the ecosystem balance, encourages wildlife migration, and reduces biodiversity.

There are several ways to manage the agricultural system so that the farmers can maintain the ecosystem balance of the ecosystem and are economically sovereign. First, farmers can optimize the use of agricultural land by intercropping. It will help minimize agricultural land use and maximize the number of crops planted. Moreover, it will reduce the use of pesticide fertilizers and maintain the forest habitat. Second, farmers can grow various perennial plants such as coconut, cashew, and nutmeg. Thus, the harvest season will form a sustainable harvest cycle (see Figure 3). This strategy also increases the farmers' economic resilience considering the market price. Implementing these strategies will minimize the vulnerability of farmers. As a result, farmers' income tends to be stable (see Figure 2). Poor management will result in poor water quality, soil surface, and drinking water resources. It would, then, disrupt the aquatic and terrestrial ecosystems (Smalling et al., 2021).

In this case, the Lotka-Volterra (L-V) model's prediction was supported by empirical data from North Buton District, Southeast Sulawesi, Indonesia. The income of a farmer in a village in North Buton Regency throughout 2020 is presented in figure 4. The dynamics of farmer income followed the L-V model cycle, which illustrated the relationship between prey and predators (see Figure 2). The data taken included crop type (coconut, nutmeg, cashew, and rice), area, quantity, prime harvest age, crop year, plant age, and intercrop (see Table 1). Besides, total crop yields and annual farmer income were analyzed (see Table 2).

Table 1. Data on the crop types in Waode Kalowo, North Buton, Southeast Sulawesi

No.	Crop type	Quantity	Crop year	Harvest time in a year	Plant age	Intercrop	Land area (Ha)
1	Coconut	600	6 years	three times	± 100 years	Coconut and nutmegs	6
2	Nutmeg	50	3 years	three times	60-70 years		0.33
3	Cashew	150	3 years	one time	50 years	None	1.5
4	Rice	-	-	one time	110-120 days	None	1.5
				Total			9

Source: Interview with Aznin (a farmer in North Buton) on 20 February 2021

Table 1 shows several types of crops. The area of cultivated land plays a significant to the crop yields and farmers' income. The wider the land was cultivated, the more crops were grown. Around 600 coconut trees could be grown in 6 hectares. Besides, 50 trees of nutmeg could be grown in an area of around 0.33 ha. Thus, the total area for growing coconuts and nutmegs was 6.33 hectares.

Nevertheless, the field research showed that only 6 hectares were needed for growing coconuts and nutmegs due to "intercropping" (coconut and nutmeg trees could be planted in the same area with a certain spacing). The spacing between coconut trees was 10 meters, while the nutmeg trees were 4 meters. This method could reduce deforestation for agricultural land use covering an area of 0.33 Ha. The intercropping could not be applied in cashew and rice; therefore, the total area cultivated was 9 Ha.

Table 2. Total of crop yields and farmers' income in Waode Kalowo, North Buton in 2020

No.	Crop type	Month	Quantity	Market price (IDR)	Crop yield (Kg)	Income (Rp)
1	Coconut (copra/100kg)	March	8,100	600,000	2,025	12,150,000
		June	7,900	800,000	1,975	15,800,000
		September	5,500	900,000	1,300	11,700,000
		December	2,500	1,020,000	600	6,120,000
2	Nutmeg/mace (1kg)	February	-	30,000	1,250	37,500,000
			-	180,000	125	22,500,000
		June	-	30,000	1,120	33,600,000
			-	160,000	112	17,920,000
		October	-	30,000	610	18,300,000
			-	180,000	61	10,980,000
3	Cashew (1 kg)	October	-	13,000	561	7,293,000
4	Rice (1 kg)	April	-	20,000	1,500	30,000,000
Total						223,863,000
Monthly average farmers' income						18,655,250

Source: Interview with Aznin (a farmer in North Buton) on 20 February 2021

The harvest occurred seven times in a year: February, March, April, June, September, October, and December. The coconuts could be harvested four times during the year, nutmeg was harvested three times, and cashew and rice were only harvested once. From March to June, the coconut yield was quite abundant; It reached 8,100 to 7,900 pieces. However, it started declining in September to 5,500 pieces and declined drastically in December to 2,500 pieces. The total coconut yield reached 8,100 pieces (2,023 kg of copra) in March, but the market price of copra was only IDR600,000 per 100 kg. Therefore, the farmer's income was IDR12,150,000. In June, the yield was lower, only 7,900 pieces (1,975 kg of copra), but the market price was higher, which was IDR800,000 per 100 kg. Therefore, the income in June exceeded the income in March, IDR15,800,000.

Nutmeg was harvested three times a year: February, June, and October. Both nutmeg seeds and mace could be sold in the market. In February, the nutmeg seeds yield was 1,250 kg, and the market price was IDR30,000/1 kg. Therefore, the farmer's income was IDR37,500,000. The mace yield was 125 kg, and the market price was IDR180,000 / 1 kg, so the income was IDR22,500,000. The total income, both of the seeds and mace, in February was IDR60,000,000. Despite the environmental conditions (such as rainfall) and the number of crop yields, the varying market price also determined the farmer's income level.

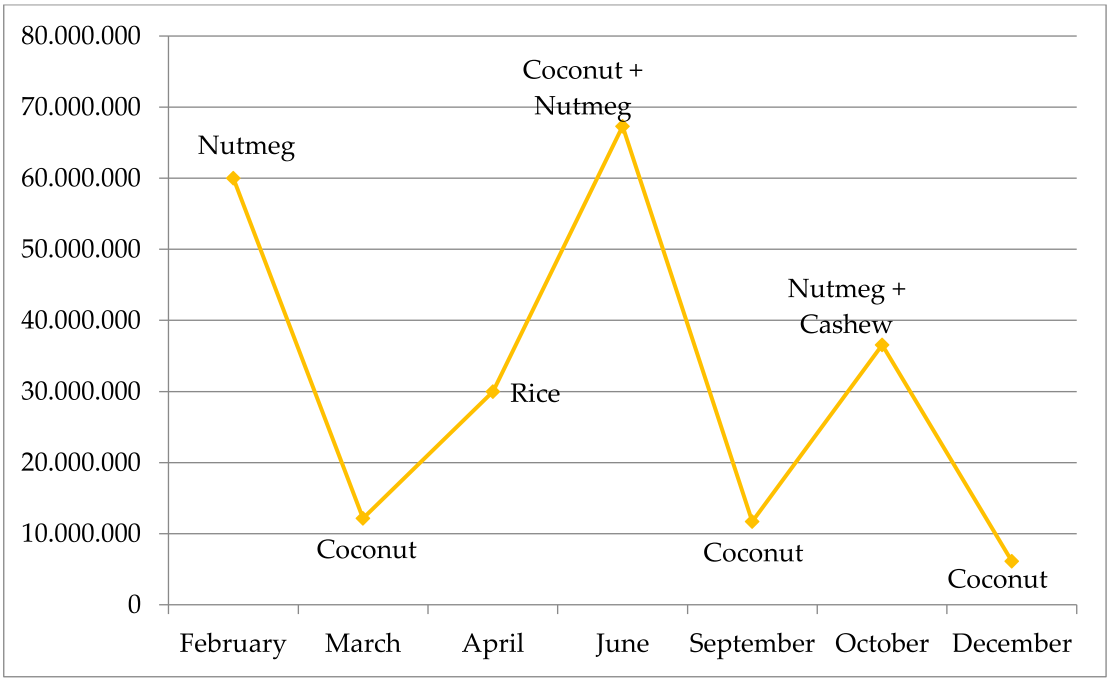

Figure 4. The dynamic of farmers' income in 2020

Growing a certain number of perennial plants can improve the economic resilience of the agrarian community. The plant's age is closely related to the length of time a plant can bear fruit. The longer the productive age of a plant, the better the farmer's economic resilience. If farmers grew several perennial plants that can be harvested numerous times, their economic resilience would be stable because it would form a good harvest cycle. The harvest cycle minimized the chances of a decline in farmers' income due to low market prices or a declining crop yield. If the coconut yield decreased or its market price was low, the other crops (such as nutmeg) could stabilize their income. Besides, the harvest cycle also increased farmers' income, as presented in Figure 4. The peak trend was in June due to double crop yields (coconut and nutmegs). The total income was IDR67,320,000. The total income in a year was IDR223,863,000, with an average monthly income of IDR18,655,250.

In February, the farmer's income was IDR60,000,000 (nutmeg) and decreased in March to reach IDR12,150,000 (coconut). However, it increased in April by IDR30,000,000 (rice) and reached its peak in June of IDR67,320,000 (coconut and nutmeg). The trend was decreasing in September, reaching IDR11,700,000 (coconut) but followed by an increase in October to IDR36,573,000 (nutmeg and cashew). The lowest point of farmer's income was in December of IDR6,120,000 (coconut). In brief, the data presented followed the dynamics of the L-V model (see Figure 2).

CONCLUSION

In many countries, agriculture has been the primary income source and the backbone of their economy and prosperity. Food demands will keep increasing annually due to the increasing number of human populations. On the other hand, drought or high rainfall due to extreme weather will adversely affect food production, forest, and environmental degradation. Therefore, it will affect the instability of farmers' income. This study found a close relationship between agricultural production and agricultural community income, following the dynamics of the Lotka-Volterra (L-V) model.

The theory explained that when the harvest is abundant (the market price is stable), the farmers' income will increase and vice versa. This research found that the crop was fluctuating, and it affected the farmers' income stability. The economic resilience of agrarian communities could be improved by growing a certain number of perennial plants. The age of the plant is related to its fruit-bearing and yield. The longer the productive age of a plant, the better the farmers' economic resilience. If farmers intercrop several types of productive crops, they could reduce deforestation. Besides, it maximized the number of the crop in agricultural land. Therefore, it would form a sustainable harvest cycle, and farmers' economic resilience will be stable. Moreover, it also balanced the natural ecosystems, agriculture, and a sustainable economy.

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