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Integrated Circular Farming and Supply Chain for Rural Economic Community Resilience

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Abstract: Establishing a sustainable economy to ensure food security in rural communities presents a significant challenge amid global economic instability and the threat of a food crisis. Integrated supply chains and circular economy models have emerged as strategies to enhance economic resilience. However, their application in rural agricultural communities is still limited. This study addresses this gap by developing an integrated supply chain and circular economy principles to strengthen the economic resilience of rural communities. Using a system thinking approach and Powersim software, the study simulates and quantifies the model's impact. Simulation results show that 1 hectare can produce 45,300 kg of sorghum per harvest, or 122,310 kg/year. This output can produce 13,590 kg of sorghum grain, 110,079 kg of silage, 44,032 kg of manure, and 30,822 kg of organic fertilizer. The integrated system generates gross annual revenues of $38,240 and incurs $26,243 in operating costs, resulting in a yearly net profit of $11,996. Financial analysis reveals a net present value (NPV) of $124 in the third year, a 10% internal rate of return (IRR), and a payback period (PBP) of 2.48 years. These findings highlight the potential of integrated agricultural systems in promoting rural economic resilience and sustainable farming practices.

Keywords: sustainable agriculture, system dynamics, circular supply chain, rural economic.

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INTRODUCTION

A sustainable economy for food security in rural communities is a critical issue, specifically during challenges such as climate change, population growth, economic instability, and resilience to the threat of a global food crisis. According to the 2024 Global Report on Food Crises (GRFC), a tipping point was attained in 2023, with the number of people experiencing acute food insecurity increasing sharply to 282 million in 59 countries. This significant increase, including an extra 24 million people compared to the previous year, was primarily caused by conflict, economic crises, and climate change. Conflict remains a major cause of death in 20 countries, with nearly 134.5 million experiencing acute food insecurity. Furthermore, economic shocks, including the impact of the Covid-19 pandemic and wars, were the main the impact of the COVID-19 pandemic and wars, were the main drivers in 21 countries, affecting approximately 75.2 million. Extreme weather was a major factor in 18 countries, with more than 71.9 million affected (FSIN & GNAFC, 2024).

Global food crises have a severe impact on the young generation and women because over 36.4 million children less than five years of age are chronically malnourished in 32 countries. Additionally, a total of 9.8 million experience severe wasting initiated by the most life-threatening form of malnutrition. In 2023, more than 705,200 people were at the worst malnutrition level and risk of starvation, representing the highest number in the 2024 GRFC report. This situation is worsened by the high dependence of low and middle-income countries on food imports and agricultural inputs, as well as the existence of inter-state conflicts, including the type experienced in Ukraine (FSIN & GNAFC, 2024).

An effective strategy to address food security problems is to increase the capacity of rural farming communities, which has great potential in managing global crises (FAO, 2022). Rural farming communities can be strong contributors to increasing productivity by implementing integrated farming, diversification of agricultural products, mechanization, supply chain integration, and circular farming strategies (Rahmann et al., 2021). However, the main obstacles to building sustainable economic resilience include the limited financial resources faced by rural communities (Ahmed et al., 2022). The income of rural communities is small, and the business management system is still conventional, leading to vulnerability to variations in market prices and uncertain weather conditions. Agricultural products are often sold at low prices because of the length of the distribution chain, as determined by the middlemen (Rahmann et al., 2021). Transportation infrastructure for the distribution of agricultural products and access to the market is inadequate in certain rural areas, leading to restrictions on the ability to sell at competitive prices (Kaiser & Barstow, 2022). In addition, extremely high expenditures related to consumption, such as fuel and other consumer goods, cause the income earned to meet only daily needs (FAO, 2022).

According to Martinez et al. (2023) and the FAO (2023), circular farming is a useful concept for increasing the economic resilience of rural communities. Circular agriculture optimizes the reuse of natural resources to minimize the use of chemicals while strengthening the economic resilience of communities (FAO, 2022; Martínez, 2023). This approach promotes farmers' self-reliance by increasing their capacity to adapt to market fluctuations and climate change, while promoting economic growth and sustainable preservation of rural ecosystems. The concept of circular agriculture emphasizes the recycling of agricultural resources and waste to create a sustainable production system, and is able to improve soil fertility. Practices such as using agricultural waste for animal feed and organic fertilizers have been proven to reduce farmers' production costs (Gupta et al., 2020). In addition, the conversion of livestock waste into biogas can create alternative energy sources, while organic material from plants is utilized as natural fertilizer. This concept can also lower operational costs and reduce environmental impact (Gupta et al., 2020; Wang et al., 2020).

Previous studies conducted by Chiaraluce et al. (2021) and Xin et al. (2021) revealed that the unification of agricultural and livestock supply chains can encourage local economic growth while increasing the effectiveness of agricultural production processes. The entire production chain, from the provision of raw materials, processing processes, to the distribution of final products can experience performance improvements through a continuous integration system (Chiaraluce et al., 2021; Xin et al., 2022). In addition, the application of digital technology in the supply chain plays an important role in cutting production time and operational expenses through a real-time monitoring system of production processes, market fluctuations, and inventory management. The collaboration established between farmers, raw material providers, distributors, and retailers through this integration can not only minimize waste of resources but can also ensure the quality and quantity of production to reach consumers (Xin et al., 2022). The efficiency resulting from this integrated system has an impact on reducing production costs and increasing profits significantly, thereby indirectly improving farmers' standard of living (Maridjo & Mudayen, 2023). Furthermore, this integrated supply chain system can open up wider market access and price stability for rural consumers, create new jobs, and can strengthen the foundations of the regional economy (Singh-Peterson et al., 2024). Therefore, the concept of an integrated supply chain is still relevant to improving the economic resilience of rural communities because this concept promotes increased synchronization in various stages of production, processing, distribution, and marketing (Singh-Peterson et al., 2024; Xu et al., 2021). All stakeholders in an integrated supply chain, including end consumers and farmers, work together to minimize waste and improve efficiency (Chiaraluce et al., 2021; Singh, 2022).

Various aspects of economic resilience include food self-sufficiency, economic sustainability, resource accessibility, soil quality for environmental sustainability, and community participation, which need to be independent, organized, and professional (Ologunde et al., 2024). The presence and operation of local institutions, such as farmer groups, farmer group associations, cooperatives, and farmer associations, will increase their capacity to cooperate and gain access to markets. Agricultural institutions can increase their accountability for agri-farm management and obtain easier access to bank credit (Ahmed et al., 2022).

The majority of previous investigations on circular farming and integrated supply chains are still at the conceptual and partial levels. No available source has discussed the influence of circular farming integration with the supply chain on the improvement, resilience, and sustainability of the community-based rural economy (Badagliacca et al., 2024; Chiaraluce et al., 2021). Consequently, this study is important and can contribute to improving the economic resilience of rural communities through an integrated system. The model of circular farming integration with the supply chain is used to promote food security and sustainable income among rural communities in a manner that considers economic sustainability, food independence, access to resources, environmental sustainability, zero waste, and community participation. The integration can facilitate the use of waste from each production process and supply, generating an interconnected cycle that releases no waste. This study has three principal objectives. First, develop a model of an integrated supply chain and circular farming to enhance the economic resilience of rural communities; Second, examine the impact of integrating agriculture on the economic sustainability of rural communities; Third, determine income generated by rural farmer groups through process integration.

The dominant businesses in rural communities in low and middle-income countries are the agricultural and livestock sectors, which remain partial and require more professional management. Farmers in the small-scale livestock industry often suffer significant losses during fattening and breeding because the processes are time-consuming, while the funds used are only minimally available.

Limitations in the discussed sectors prompted this study to offer the concept of an integrated model of feed cultivation and the management of livestock wastes derived from corn, sorghum, Indigofera, cassava, and other plants. Wastes are used as an ingredient in wet and dry animal feed in the form of fermented silage. Furthermore, livestock produces waste/manure that can be processed into organic fertilizers for feed cultivation, forming an integrated cycle or ecosystem capable of generating more profits for farmers (Ren et al., 2024). Four ecosystems formed from this process will become small-scale pioneer businesses, including animal feed, livestock, organic fertilizer, and supporting industries such as cages and machinery.

The process constituting the small-industry cycle is based on integrated agri-farming (Dolci et al., 2024; Xin et al., 2022). The first business process was limited to animal feed cultivation by farmers on available land.

This includes growing sorghum or corn plants, with advantages such as high protein value, 3–4 harvesting times, 6–8 tons/ha productivity, and generation of seeds that can be an income source for farmers (Kurniasari et al., 2023). The second is the production of livestock meat, namely beef and goat. At the same time, the third comprises the development of organic fertilizers used for sorghum plants and traded according to production capabilities (Ren et al., 2024).

The industrial system integration model is expected to promote farmers' economy. Agricultural waste management and livestock waste can be processed as new economic sources for farmers. This is also known as the circular economy (CE) model, which was first introduced by Professor Walter Stahel in 2010 in a book entitled "The Performance Economy". The CE model is different from the concept of an integrated supply chain, featuring the connection of various functions and processes in the supply chain of a company or organization to produce more efficient and practical cooperation. An integrated supply chain generally aims to provide added value to companies by improving efficiency, flexibility, and competitiveness while minimizing costs and risks.

Pomoni et al. (2024) introduced several references for the concept of CE and how the transition from a linear system to a more circular system is a sustainable practice in resource and waste management (Pomoni et al., 2024). According to Momeni et al. (2024), the Integrated Circular Economy Model for Agriculture and Livestock (ICEMFSR) is gaining more attention as an effective medium for allocating agricultural resources through a combination of contingency assessment and linear multi-objective programming (Momeni et al., 2024; Wang et al., 2022). The application of this model significantly improved the level of sustainable development. Martinez et al. (2024) stated that CE offers great economic, environmental, and socio-agricultural sustainability potential. However, studies on CE focused only on the industrial sector, leaving a significant gap in the analysis of the sustainable circulation model in agriculture (Martínez, 2023).

Dolci et al. (2024) study Industry 4.0, integration, and CE has received great attention to enable sustainable and innovative manufacturing practices. The results contribute to a comprehensive understanding of the interaction between Industry 4.0 and CE while paving the way for future investigations and practical applications in manufacturing (Dolci et al., 2024). Hakim et al. (2017) used a dynamic system method comprising five key elements of the agro-industrial integrated system: cassava-agroindustry, cassava sales by farmers, cassava stocks at the trader level, cassava sales by traders, and cassava stocks at the industrial level. A systemic perspective recommends optimizing the integration process among farmers, traders, and agribusiness as a crucial policy in the development of cassava agronomy (Hakim et al., 2024).

Figure 1 shows that there is a research trend towards the level of developing food security in rural communities based on Industry 5.0. This approach is a new paradigm in rural economic development that integrates digital technology with the principle of human-centred development (Bissadu et al., 2024; Suleiman et al., 2022). The use of technologies such as artificial intelligence (AI), Internet of Things (IoT), and robotics can significantly increase production efficiency in the agricultural sector and small industries in rural areas (FAO, 2023). The application of IoT can also be applied to agricultural irrigation systems, especially in greenhouse farming. In addition, it is no less important to do to improve the rural economy, namely how to strengthen local capacity, and improve the quality of life of rural people through education, health, and community empowerment (Rahaman et al., 2024), Increased understanding of the importance of applying environmental sustainability principles through an integrated production system that is environmentally friendly in rural economic activities (Diantini et al., 2023). Furthermore, strengthening digital connectivity is an important key to opening market access, where the development of internet infrastructure and the adoption of e-commerce platforms can be a bridge for agricultural products. Supporting local entrepreneurship is crucial for expanding market access and capital for small and medium-sized enterprises (SMEs) in rural areas. Close collaboration between governments, the private sector, and civil society is also essential for creating an ecosystem that supports innovation and inclusive economic growth in rural areas (Meinzen-Dick et al., 2004). The objective of this concept is to enhance rural economic productivity and guarantee that the advantages are distributed equitably throughout the local community.

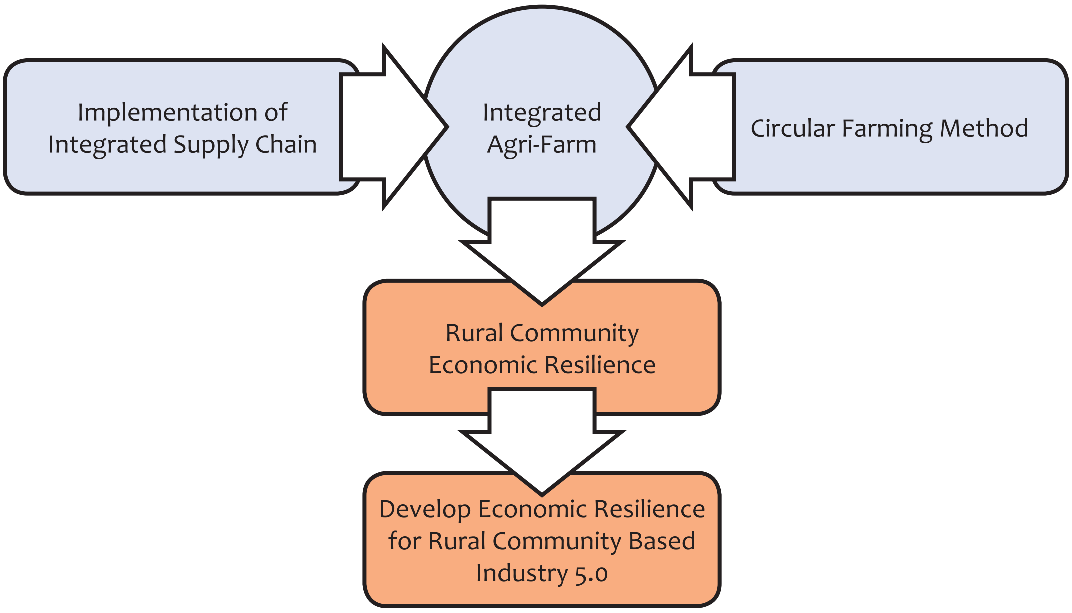

Figure 1 Model of Economic Resilience Development in Rural Communities

Several studies have identified that investigations regarding CE are mainly at the conceptual level, although the idea technically became known in the mid-1980s. Therefore, the CE method in the supply chain system still needs to be improved, specifically in the agricultural industry, which primarily uses raw agricultural materials in the production process. In addition, the relatively slow adoption of CE in agricultural production or supply chain systems is due to implementing a large-scale sustainable development method focused on balancing the economic, social, and environmental aspects. In addition, more effort is needed to achieve sustainable development (Yusriana et al., 2023). In the context of supply chain systems, topics related to sustainable development have been investigated extensively. The topic of this study is related to the implementation of a sustainable development method in the supply chain system, including in the agroindustry (Novra et al., 2022). Green supply chains have also been widely discussed, particularly regarding products that cannot be recycled (Novitasari et al., 2021). In general, the topic has not applied a closed-loop system to each supply chain actor; therefore, the control of by-products and waste in agroindustry tends to remain a local champion. This concept is depicted in the master plan agri-farm integration model shown in Figure 2 (Gupta et al., 2020; Nababan & Regina, 2021).

Integrated farming and CE can be achieved by implementing sustainable food supply chain networks that minimize waste and optimize resource usage. The CE model in the agri-food sector increases production and consumption by reusing and assessing wastes and by-products. Stakeholders at different levels can work jointly to improve the supply chain using CE solutions, such as innovative packaging materials, to minimize food waste (Vodenicharova & Mihova, 2023). Quantitative information is required to prioritize circular options and gather consumer preferences to design more profitable and attractive circular initiatives. The implementation of circular supply chain management in the agricultural sector, as observed in Vietnam, showed promising results regarding the development of value-added products and sustainability improvement. By implementing a circular strategy, the agro-industrial sector can reduce pollution, optimize processes and resources, and improve environmental and economic indicators. Additionally, CE can improve the sustainability of agri-food supply chains, such as in Europe, which is leading in studies and policy development (Chiaraluce et al., 2021). Any of the stated references did not specifically mention "integrated agri-farming for circular farming and integrated supply chain for sustainability economic rural community resilience". Therefore, this study aims to design a circular farming model for the agri-farm sector, with a specific focus on the reuse and valorization of waste and by-products from agriculture and livestock that are integrated from both processing and supply aspects.

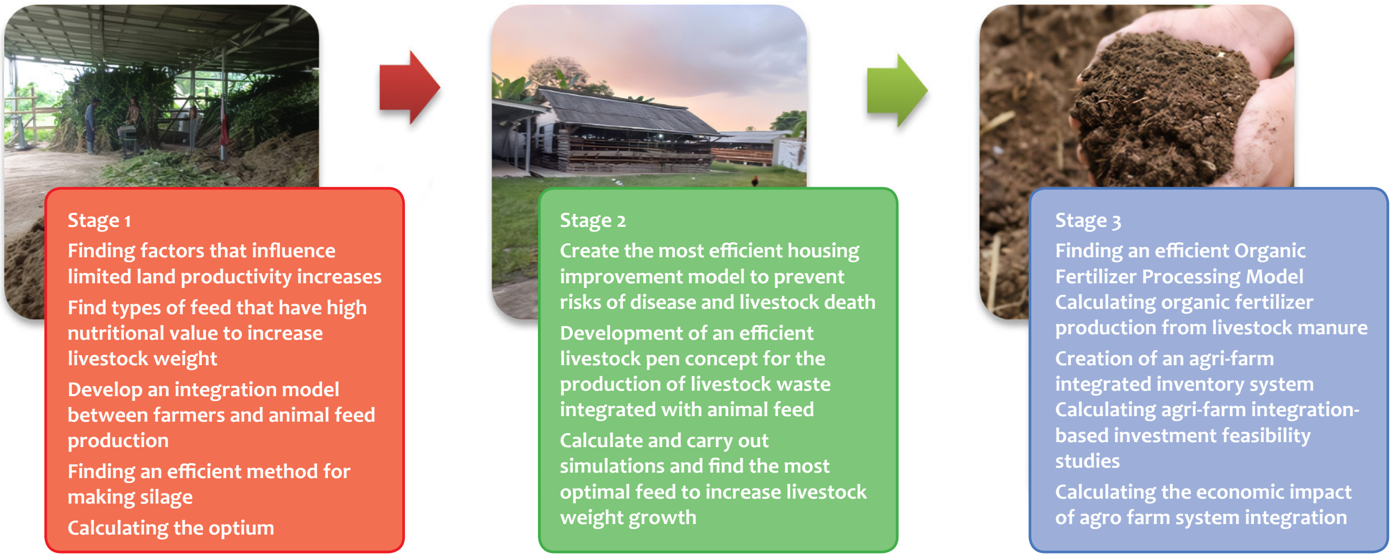

Figure 2 Study Roadmap of Agri-Farm Integration Model

METHODS

A literature or systematic review was conducted in the early part of this study, generating results in the form of an integrated agri-farm model based on CE and an integrated supply chain. Model development started with the identification of factors affecting the increase in the productivity of animal feed production land, including the discovery of feed containing the best nutrients that can be used in the livestock fattening process. These factors were determined from literature studies and finalized through focus group discussions with experts. Furthermore, the results were experimentally tested on a limited land area of 1 ha and quantitatively calculated using the dynamic system method. In circular farming, the integrated model leads to interactions among various elements of sustainable agriculture, such as crops, animals, and energy, in a closed cycle. This integrated supply chain model can be developed into an integrated agri-farming small-industry model, as shown in Figure 3.

The effect of the integrated agri-farm in Figure 3 was evaluated using a dynamic system model with the Powersim software. System thinking software, such as Powersim 10.0, is highly relevant for building, simulating, and analyzing dynamic system models (Wang et al., 2022). Regarding the discussed perspective, the circular system optimizes resource use by recycling nutrients and reducing waste. Through simulation and analysis, users can evaluate the efficiency of the system and the environmental impacts of different scenarios. The benefits include higher resource efficiency, waste reduction, and better sustainability, helping farmers plan systems that are more durable and adaptive to environmental changes (Ada, 2022; Wang et al., 2022).

The Powersim software can be used to develop an efficient livestock cage concept for the production of livestock waste integrated with feed and to calculate and carry out simulations to find the optimal feed for increasing livestock weight growth. Additionally, it is used to design an efficient Organic Fertilizer Processing Model, develop an agri-farm integration inventory system, perform a feasibility study of investment based on agri-farm integration, and evaluate the economic impact of the integration of agri-farm systems.

Figure 3 Small industry Conceptual Model Based on Integrated Agri-Farming

The methods used in the data collection process in this study included direct interviews, experiments, and focus group discussions. Literature studies, interviews, and field tests were used to measure land productivity, as well as production levels of sorghum, silage, livestock manure, and compost manure. Productivity was evaluated by the amount of production obtained from the land in one harvest, and crop yields were estimated based on weight in kg/ha. The weight of silage, animal manure, and organic fertilizer was calculated using measuring instruments. Calculations of investment capital, operational costs, prices, and potential savings were obtained from direct interviews with farmer groups in the field. All interview data were approved orally and in written form by the head of the farmer group community. Agreement for participation in the study process and the authenticity of data were proven through participant consent. This study was conducted on 1 ha of land belonging to the farmer groups "Smart Siloka Agri-Farm" and "Maja Farmer Community" in Banten Province, Indonesia. Additionally, approval was received from the ethics committee of Sultan Ageng Tirtayasa University (Ref 2024/08/14/1).

Several factors were considered when designing a model based on the results of interviews in focus group discussions, farmer groups, and field tests. The research team conducted discussions with soil experts, livestock experts, sorghum farmers, and animal feed entrepreneurs to identify the key factors in Table 1. All factors have been validated through in-depth discussions in focus group discussions with experts, field practitioners, and farmer groups to ensure their relevance to the actual conditions of the field.

Table 1 Factors Influencing the Agri-Farm Integration Model

Level Variable	Auxiliary Variable	Variable Constant	Value	Source
Sorghum	Prod_Sorghum	Land_Area	1 ha	Field Measurement and Interview (Najam et al., 2021)
	Prod_Silage	Fract_Prod_silage	0.9	Field Measurement and Interview (Kurniasari et al., 2023)
	Sorgh_Grain	Fract_Grain	0.1	Field measurement and interviews (Kurniasari et al., 2023)
	Productivity	Water	0.1	(FAO, 2020; World Bank, 2021)
		Land_Prepra	0.1	(FAO, 2020; World Bank, 2021)
		Fract_Pest	0.1	(FAO, 2020; World Bank, 2021)
		Weeding_Land	0.01	(FAO, 2020; World Bank, 2021)
	Ferti_Productiv	Fract_Fertilis	0.2	Field Measurement and Interview (Alnaass et al., 2021)
Amount_Silage	Need_Silage	Fract_Feed	0.9	Field Measurement and Interview (FAO, 2021)
	Fail_Silage	Fract_Fail_Silage	0.1	Field measurement and interviews (FAO, 2022)
	Amount_Goat	Consumtion_Silage	3 kg/day	Field measurement and interviews (Kurniasari et al., 2023; Ren et al., 2024)
Feed_Goat	Growth_Goat	Fract_Growth_Goat	0.6	(FAO, 2020)
	Waste_Goat	Fract_Waste	0.4	(FAO, 2020; World Bank, 2021)
Stock_Waste	Fertility_Fail	Fract_Fail_Fertility	0.3	(Alnaass et al., 2021)
	Product_Fertilility	Fract_Fertility	0.7	(Kurniasari et al., 2023)
Stock_Ferti	Demand_Fertility	Fract_Demand_Ferti	10,000 kg/ha	Interview, Field Measurement, and Interview (Kurniasari et al., 2023)
	Fertility_ Productiv	Fract_Prod_Fertility	0.2	Interview, Field Measurement, and Interview (Kurniasari et al., 2023)

This study uses the systems thinking method for model development. The supply chain and circular farming integration model begins with the construction of a Causal Loop Diagram (CLD), then the creation of a Stock and Flow Diagram (SFD) using Powersim software. The Causal Loop Diagram (CLD) is used to visualize the interactions between variables forming closed causal loops that affect each other. Positive relationships are denoted by R (Reinforcing), while negative relationships are marked by B (Balancing). The CLD framework starts with sorghum production, which connects to Silage Production, Silage Needs in Livestock, organic fertilizer production from waste, and the use of fertilizer to increase land and sorghum productivity.

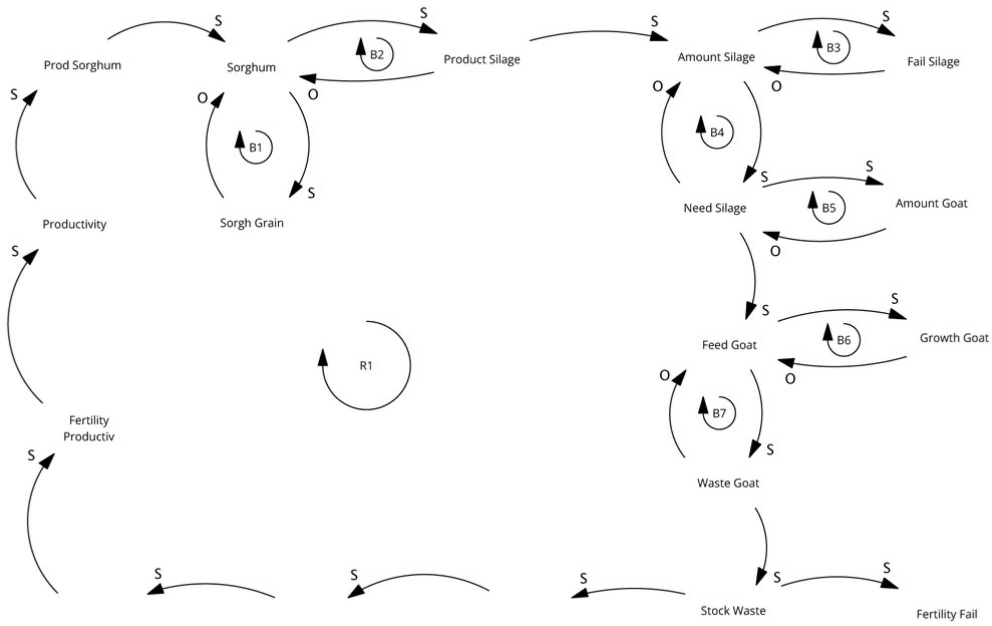

Figure 4 Causal Loop Diagram

Figure 4 reveals one reinforcing feedback loop (R_1), characterized by a positive-positive relationship between variables and ten balancing feedback loops (B_1 to B_{10}), each representing a positive–negative relationship. The reinforcing loops (R_1) reflect an interconnected system where variables such as productivity, Prod_Sorghum, Sorghum, Product_Silage, Amount_Silage, Need_Silage, Feed_Goat, Waste_Goat, Stock_Waste, Product_Fertility, and Stock_Fertility mutually amplify one another. In contrast, the balancing loops (B_1 – B_{10}) regulate these processes by introducing negative feedback, ensuring system stability.

Furthermore, this study developed a Stock and Flow Diagram model comprising variables affecting the agri-farm integration model, as shown in Table 1. All factors were included in the model and simulated using Powersim 10.0 and the Euler one-step method. To form an integrated system in the stock and flow model, it is necessary to simulate the effect of using 1 ha to produce sorghum biomass, sorghum seeds, and silage, which can be converted into manure.

The Stock and Flow Diagram of the agri-farm integration model in Figure 5 shows that sorghum productivity influenced by weeding, land preparation, pesticide spraying, water, and organic fertilizer applications can increase total production by 51% from 30 to 45.3 tons for one harvest. Therefore, harvesting is performed three times annually, and the amount of sorghum production will be 135.9 tons/year/ha.

Table 2 Powersim Simulation of Cashflow Sorghum Material Flow into Organic Fertilizer

Hectare	Sorghum Production (Kg)	Sorghum Biomass (kg)	Silage Production (Kg)	Waste Production (Kg)	Fertilizer Production (Kg)	Sorghum Grain (Kg)
1	135,900	122,310	110,079	44,032	30,822	13,590
2	271,800	244,620	220,158	88,063	61,644	27,180
3	407,700	366,930	330,237	132,095	92,466	40,770
Total	**815,400**	**733,860**	**660,474**	**264,190**	**184,933**	**81,540**

Table 2 shows that, by using 1 ha of land with a productivity rate of 51%, production could increase from an average of 30.000 kg/ha to 45,300 kg/ha for one harvest. Sorghum is harvested three times a year, leading to a total production of stems, leaves, and grains measuring 135,900 kg/ha, 271,800 kg for 2 ha, and 407,700 kg for 3 ha, respectively. Furthermore, the production of Sorghum Biomass, Sorghum grain, silage, animal manure, and organic fertilizer reached 122,310 kg/ha, 13,590 kg/ha, 110,079 kg/ha, 44,032 kg/ha, and 30,822 kg/year, respectively. Meanwhile, the need for organic fertilizer was only 10 tons/ha, leading to leftovers that farmers could sell to increase income by 274 Kg/ha or 822 Kg/ha/year.

The simulation results showed a quantity reduction starting from the production process of sorghum, silage, and animal manure until conversion into organic fertilizer. Furthermore, the simulation was conducted in three stages using land areas of 1, 2, and 3 ha, where sorghum production with three harvests annually reached 135,900, 271,800, and 407,700 kg/year, respectively. The total amounts of sorghum biomass, grain, silage, animal manure, and organic fertilizer production are presented in Figure 6.

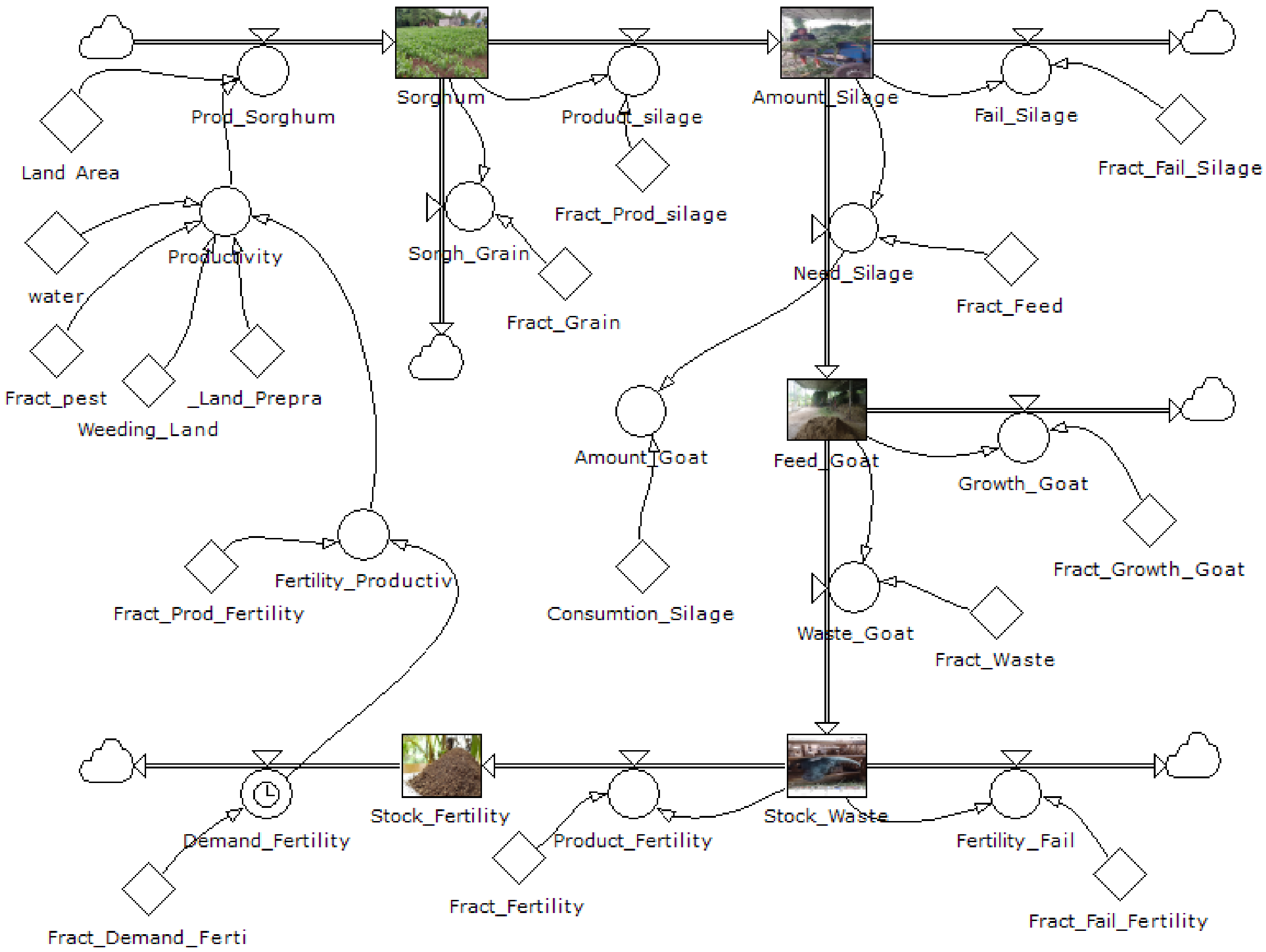

Figure 5 Stock and Flow Diagram

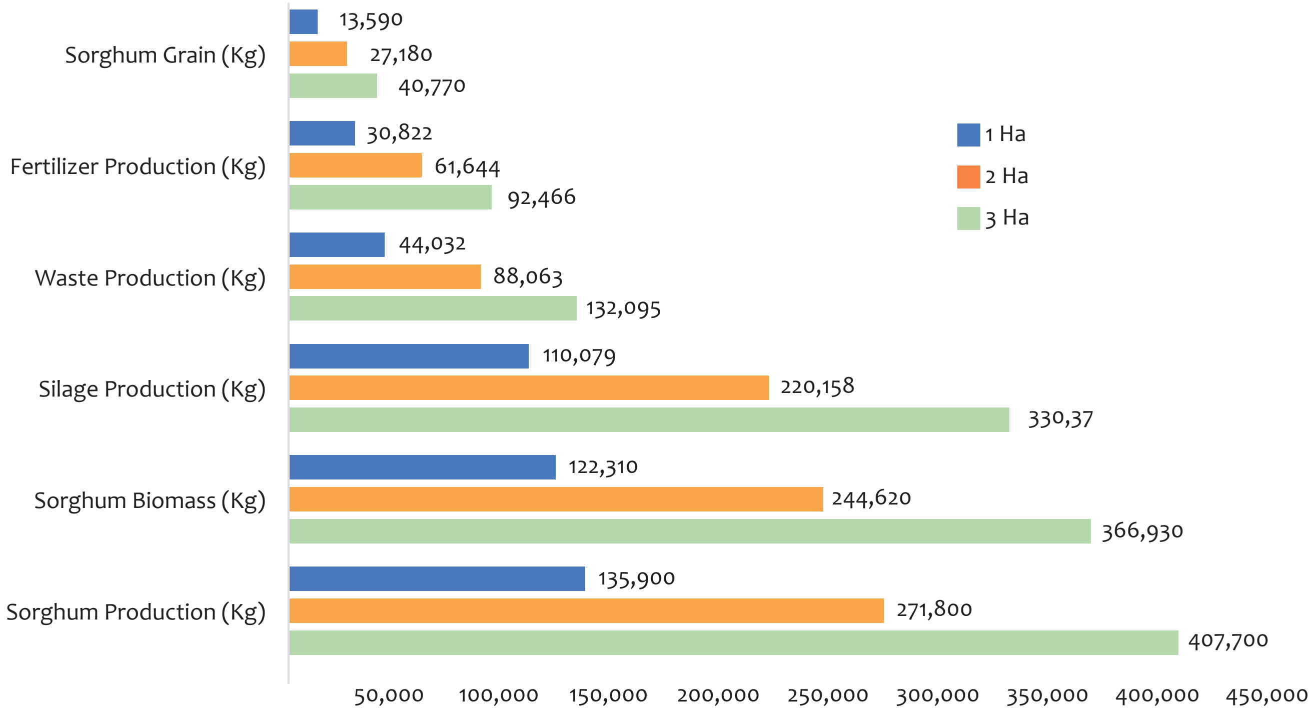

Figure 6 Powersim Integrated Agri-Farm Simulation Graph

RESULTS AND DISCUSSION

In this study, land cultivation (Land_Prepra) helped increase the aeration of soil structure and root growth, while proper watering (water) provided sufficient water for the plant, and pest spraying (Fract_Pesti) was conducted to control pests and reduce crop damage for yield enhancement. Additionally, weeding (Weeding_Land) was performed to minimize competition from weeds, which could reduce the availability of water, light, and nutrients for key crops, and the application of Organic Fertilizers (fraction _ fertility) would provide nutrients and increase soil fertility in the long term.

Interventions are crucial to increase land productivity to maintain nutrient and soil pH, prevent pests, and increase plant fertility. Five critical factors included in the model and simulated in this study to increase land productivity were Land_Prepra, Water, Fract_Persti, Weeding_Land, and Fertility. Additionally, the type of sorghum cultivated was a new superior variety (VUB) known as Bioguma Sorghum, which has the characteristics of a plant height reaching 266 cm, a biomass weight of 54.30 tons/hectare, a sap volume of 122 ml, a potential yield of 9.3 tons/ha, a brix content of around 15%, and resistance to leaf rust and stem rot (Wirawan et al., 2024). The planting distance that provided the best growth for sorghum plants was 70 cm × 20 cm (Najam et al., 2021).

The results of the simulation showed that the land areas ex amined were 1 ha, 2 ha, and 3 ha. Meanwhile, the levels of productivity at 10%, 10%, 10%, 1%, and 20% were affected by the variables Land_Prepra (Brady et al., 2008), Water (FAO, 2022), Fract_Pesti (Oerke et al., 2006), Weeding_Land (Kurniasari et al., 2023), and Fract_Fertilis, respectively (Alnaass et al., 2021). The total biomass production was 122,310 kg, 244,620 kg, and 366,930 kg, while the total grains were 13,590 kg, 27,180 kg, and 40,770 kg for 1, 2, and 3 ha of land, respectively.

To meet the nutritional needs of livestock, ruminant farming businesses, such as the rearing of cattle, goats, and sheep, face the problem of insufficient feed availability. Green feed ingredients are difficult to access during the dry season; therefore, innovation is required to prepare fermented feed products, such as silage. Four simple steps were used to prepare the silage: first, the stems and leaves were dried for two days, then chopped with a shredder to a size of 3–10 cm. The second solution consists of one liter of water and a mixture of concentrates and probiotics, including Molasses and Effective Microorganisms for Livestock (EM4). Third, the solution was sprayed onto the chopped silage material, and concentrated feed, such as bran, was added. Fourth, the silage material is transferred into a container such as a barrel or plastic with a thickness of approximately 40 cm and compressed to minimize the presence of air gaps. The anaerobic nature of this procedure requires closing the barrel tightly and allowing silage to ferment for three to seven days.

The raw material commonly obtained from sorghum plants for silage production comprises 20%-30% leaves and 60%-70% stems, which greatly affects the quality of the product. Many fibers and sugars are present in the stems, thereby playing an important role during the fermentation process. The sugar content in the bars helps to create ideal bacterial fermentation conditions, leading to the production of lactic acid, which helps preserve silage. According to Kristamtini et al. (2016), if sorghum stems and leaves are used effectively, the silage produced has a high nutritional value that can increase livestock weight to the maximum (Kristamtini et al., 2024).

Silage products are considered suitable for animal feed when they appear bright green and emit a characteristic ribbon aroma without showing signs of decay. According to FAO (2023), silage can increase livestock appetite and reduce bad odors from manure, while the success of production from sorghum is generally very high, with the majority presenting satisfactory results in terms of fermentation and nutritional quality (FAO, 2023). This success rate can reach more than 90% when the fermentation process is carried out correctly and through best practices. Using 45,300 kg of sorghum raw material in the form of stems and leaves, 36,693 tons of silage can be produced with a production failure rate of 1%. This implies that three sorghum harvests per year tend to produce 110,079, 220,158, and 330,237 kg of silage from 1, 2, and 3 ha of land, respectively.

The results of this study were consistent with Kristamtini et al. (2024) and Kurniasari et al. (2023) which reported the productivity of sweet stem sorghum seeds, fresh stems, as well as leaves at a level of 6.96 tons, 42.36 tons/ha, and 14.13 tons/ha, respectively in one harvest (Dinata et al., 2012). Dinata (2016) stated that the level of sorghum forage production tends to reach 75 tons per ha under optimal growth conditions (Kristamtini et al., 2024; Kurniasari et al., 2023).

The percentage of silage feed that forms waste (animal manure) in peanut goats varies depending on several factors, such as feed quality, digestion efficiency, and maintenance conditions, including undigested feed residues and waste products from metabolic processes. In general, approximately 30-40% of the feed consumed by goats is converted into animal waste and urine, while the remaining 60%-70% is absorbed by the body for energy and nutrient needs. The digestive efficiency of goats is significantly influenced by the quality and type of feed provided. Fibre-rich feeds tend to produce more impurities than digestible and nutrient-dense feeds. Therefore, it is essential to provide a balanced and high-quality feed to promote the optimal use of nutrients and reduce excessive manure production.

Based on the calculations in Table 2, about 40% of the silage feed given to goats will turn into livestock manure. From a land area of 1 hectare, it can produce 110,079 kg of silage, producing 30,822 kg of manure. If the land is managed 2 ha, it can produce 220,158 kg of silage, and 61,644 kg of drum fertilizer, while if the land is 3 ha, it can produce 330,237 kg of silage, and 92,466 kg of drum fertilizer. The production rate of this drum fertilizer is greatly influenced by the number of goats raised. The study found that each sorghum crop can support feed production for 100 goats, with a total feed requirement of 360 kg per head (3 kg x 30 days x 4 months), for a single harvest cycle of 4 months, assuming 3 kg of feed per day. These findings are in line with the research of Dinata et al. (2016) and Najam et al. (2021), which found a similar pattern in sheep, where each sheep consumed an average of 2 – 3 kg of forage per day, with 40% turning into manure (2.4 kg/day) and the remaining 40% – 50% into organic fertilizer (2.6 kg/day) (Najam et al., 2021).

The use of silage in livestock is intended to increase nutritional intake. The nutritional needs of goats are influenced by several factors, including age, weight, health condition, gender, and maintenance goals (milk, meat, or breeding production). Goats usually consume dry feed of 2% - 4% of their body weight per day (Najam et al., 2021). Goats 6 – 10 months old and weighing 20 – 35 kg need additional nutrients to support their development, by consuming feed 3-4% of their body weight. Similarly, goats aged 10 – 14 months with a body weight of 35 – 45 kg also need additional feed according to the purpose of raising the livestock, such as for the production of meat, milk, or for breeding. Next, Adult goats over 14 months old with a weight of 45-60 kg have stable feed needs and consume 3-4% of their body weight in the form of dry ingredients per day. Furthermore, the main feed ration consists of grass, legumes, concentrates, and supplements, with particular attention paid to nutritional needs for the production of milk and meat, or the conduct of breeding. Factors such as environmental conditions can affect feed consumption; goats exposed to cold may require more energy to maintain body temperature, leading to an increase in feed consumption. In addition, lactating goats require more feed than non-lactating goats to support milk production, and health plays an important role because sick or stressed goats tend to eat less than their healthy counterparts.

Using animal manure as an organic fertilizer has become a common practice in modern agriculture to improve soil fertility and crop yield. Goat manure, rich in nutrients such as nitrogen, phosphorus, and potassium, is highly valued for its contribution to plant growth. However, raw goat manure must pass through a proper composting process before it can be used effectively. According to Alnaass (2021), the composting process can convert approximately 60-70% of the original mass of animal manure into safe organic fertilizer that is useful after removing pathogens and weed seeds, serving as a rich source of nutrients for crops (Alnaass et al., 2021; Saah et al., 2022). This process can improve soil structure, water management, and nutrients. Organic fertilizers' nutritional content can be increased by regulating microorganisms and maintaining ideal humidity, aeration, and temperature during the composting process.

In manufacturing organic fertilizer from goat manure, the study used a success rate of 70% and a failure rate of 30% (FAO, 2022). The results of the Powersim simulation show that on a scale of 1 hectare of land can produce 44,032 kg of goat manure, and 30,822 kilograms of fertilizer from 300 goats/year. The composting process of goat manure takes several weeks to months, depending on factors such as the level of aeration, moisture content, and the size of the animal manure particles produced. During the process, the compost pile should remain moist without being extremely wet while ensuring sufficient air availability to prevent anaerobic conditions that can slow the decomposition of organic matter. Stirring the pile regularly helps speed up composting by ensuring an even distribution of heat and moisture. According to FAO (2022), livestock waste must be composted because the carbon-to-nitrogen (C/N) ratio is above 30, suggesting that a long time is required for biological degradation. Composting requires microorganisms, including functional bacteria and actinomycetes, that play a role in the decomposition of organic matter. In this context, waste's excellent quality of organic fertilizer is mixed with lime, dolomite, natural phosphate rock, bone meal, and microbes. Nitrogen can be added microbiologically by using the method of inoculation with N2-fixing bacteria. Inoculation of organic fertilizer with microbes was performed when the compost was manure with a C/N ratio of less than 25 and a stable temperature of 30–35°C (FAO, 2022).

Organic fertilizers prepared from goat manure have many benefits, such as increasing soil fertility, improving soil structure, enhancing water retention, releasing nutrients slowly according to plant needs, controlling livestock waste, reducing odors, and minimizing greenhouse gas emissions (Makan & Kabra, 2021). Despite supplying nutrients that are easily and rapidly absorbed, organic fertilizers can pollute the soil and water when applied excessively. Goat manure composting is a highly effective and sustainable farming method because it produces organic fertilizers as a source of beneficial nutrients that maintain soil health when appropriately managed (Alnaass et al., 2021; Ren et al., 2024).

Soil conditions and fertilization in a particular land area mainly influence the need to apply organic fertilizers to sorghum plants. Using organic fertilizers can improve soil fertility, improve soil composition, and sustainably provide essential nutrients. In this study, the amount of organic fertilizer used to increase sorghum productivity was 10 tons/ha (Pramundito & Suryani, 2024). Fertilizer application to the soil can be varied according to soil conditions and plant needs. The advantage of this compost fertilizer is that it contains potassium, nitrogen, and phosphorus, which can be easily decomposed to improve soil structure.

When applying organic fertilizer to sorghum plants, attention needs to be paid to the readiness of the land first to prevent competition for nutrients between the main crops by eliminating the remains of grass or weeds that grew earlier. Furthermore, to increase aeration and improve the structure, the soil is loosened first before the application of manure. The application of manure on ready-to-plant land is carried out using tractor machines and hoes, while still ensuring the distribution of manure evenly on ready-to-plant land. The depth of ready-to-plant tillage is 15 – 20 cm to ensure that sorghum plants obtain nutrients from the beginning of growth. Furthermore, after the tillage process is completed, sorghum seeds are planted at a predetermined distance. Likewise, a regular watering system is needed to maintain soil moisture and facilitate seed germination so that sorghum cultivation can grow properly.

Maintaining sorghum after cultivation is important because regular watering, weed removal, and pest control are necessary for optimal plant growth. To increase plant growth, additional organic fertilizers can be applied throughout the growing season, when needed (Kurniasari et al., 2023). The use of organic fertilizers encourages the formation of a sustainable economic system that is environmentally friendly, increases sustainable nutrients, and can improve soil health in the long term (Ologunde et al., 2024).

In general, the implication of the research is the formation of a sustainable and integrated business process in rural communities by optimizing the potential of considerable unused land. The integration of sorghum cultivation management and goat farming as a case study is due to the fact that this crop can be harvested 3 times a year, and its nutritional content is suitable for livestock. This integration can serve as a profitable business model for each production line, including the production of sorghum, silage, goat waste, organic fertilizer, and livestock. Silage is often used as animal feed during breeding or fattening, and the application of organic fertilizer helps enhance land productivity, while the remaining sorghum products and goat sales can increase farmers' income.

Implementation of the integrated agri-farm model leads to a 51% increase in agricultural land productivity, feed certainty for livestock, and replacement of chemical fertilizers with organic types. This generates a closed process or cycle that complements each other to ensure that feed needs for livestock are met every year. After calculating the flow of raw material from sorghum into silage products and the production of animal manure and fertilizer, the next step was to estimate the integrated agri-farm investment cash flow.

Table 3 shows the types of equipment used on an agri-farm, and the investment required to purchase the equipment is $3,467. This investment is intended to purchase a 1000 m Drip Hose for watering sorghum, one unit pump, one unit chopper machine, a battering machine for processing animal waste into fertilizer, cage modification for a capacity of 100 goats, and one unit of enclosure equipment. Additionally, the operational costs required for producing sorghum in three harvests/ha annually, silage, and goat waste are $676, $834, and $19,800, respectively. Employee and insurance costs are $4,933, leading to total operational costs of $26,243 per year, and the total investment required for agri-farm management is $29,710.

Table 4 shows that the potential gross profit that can be generated through this agri-farm integration system is $11,996/year. This profit was generated from the sale of 13,590 Kg of sorghum grain for $4,530 at $0.33/kg, 300 goats/year for $33,600 ($4.67*24kg/goat), and 822 Kg of fertilizer for $110. Meanwhile, the operational costs for 1 ha are $26,243/year, all of these prices are at the farmer level in Banten province, Indonesia, which are then converted to the dollar exchange rate (1 USD = Rp. 15,000).

Table 5 shows the calculation and simulation of NPV, IRR, and PBP, where the amount of income generated each year for 1 ha of land is $38,240, and operational costs are $26,243, producing a total annual profit of $11,996. The simulation and calculation results showed the NPV was calculated at a corporate interest rate of 10%, and the positive result was $124 generated in the third year, while the IRR was 10%, and the PBP was 2.48 years.

Table 3 Equipment Investment for Integrated Agri-Farm

No	Equipment	Price	Units	Amount	Total
1	Drip Hose	$0.33	m	1,000	$333
2	Pump	$200	Unit	1	$200
3	Chopper Machine	$500	Unit	1	$500
4	Battering Machine	$233.33	Unit	1	$233
5	Cage Modification	$20	/goat	100	$2,000
6	Enclosure Equipment	$200	Package	1	$200
Equipment Investment					$3,467
Total Operational Cost					$26,243
Total Investment					$29,710

Table 4 Cashflow Investment for Integrated Agri-Farm

No	Activity	Price (USD)	Units	Amount	Year 1	Year 2	Year 3
Income from Selling Sorghum, Goats and Fertilizer							
1	Sorghum Grain	0.33	/kg	13,590	4,530	4,530	4,530
2	Goat Selling	4.67	24 kg/goat	300	33,600	33,600	33,600
3	Goat Waste	0.13	/kg	822	110	110	110
Total					38,240	38,240	38,240

Cost of Sorghum Production							
1	Land Processing	200.00	/ha	1	200	200	200
2	Pest spraying	13.33	4 btl	4	53	53	53
3	Seedlings	3.33	kg	10	33	33	33
4	Plastic	0.13	150 kg	750	100	100	100
5	Grain Transportation	0.01	ton	13.590	181	181	181
Sub Total					568	568	568
Cost of Silage Production							
1	Plastic	0.13	/Kg	750	100	100	100
2	Electric, Water, Solar	0.01	Kwh	110,079	734	734	734
Sub Total					834	834	834
Cost of Goat Waste							
1	Goat	4.67	14 kg/goat	300	19,600	19,600	19,600
2	Cost of Supplements, Vaccines, and Medicines	66.67	3 times	3	200	200	200
3	Microbes	4.00	9 btl/ha	27	108	108	108
Sub Total					19,908	19,908	19,908
Cost of Employee							
1	Employee	200.00	person/month	2	4,800	4,800	4,800
2	Insurance of Employee	5.56	USD	2	133	133	133
Sub Total					4,933	4,933	4,933
Operational Cost (USD)					26,243	26,243	26,243
Total Profit (USD)					11,996	11,996	11,996

Table 5 Calculation of Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PBP)

Year To-	0	1	2	3	4	5
Investment	-$29,710					
Income	$0	$38,240	$38,240	$38,240	$38,240	$38,240
Operational Cost	$0	$26,243	$26,243	$26,243	$26,243	$26,243
Cashflow	-$29,710	$11,996	$11,996	$11,996	$11,996	$11,996
Cashflow Cumulative	-$29,710	-$17,713	-$5,717	$6,280	$18,276	$30,272
NPV		-$18,804	-$8,890	$124	$8,317	$15,766
IRR		-60%	-13%	10%	22%	29%
Pay Back Period (Year)			2.48			

Figure 7 shows a graph of the relationships between profits, costs, operational costs, cash flow, and cumulative cash flow. The graph signifies that in the first and second years, the investment of $29,710 did not produce a positive trend. A new positive trend is found in the third year of the investment period. Therefore, investment in integrated agri-farms comprising sorghum cultivation, along with the production of silage, livestock, and fertilizer, can provide benefits to farmers and communities. Through this integrated agri-farm, land conditions can be improved to become more environmentally friendly to ensure freedom from pollution and support the reduction of greenhouse gases (Makan & Kabra, 2021).

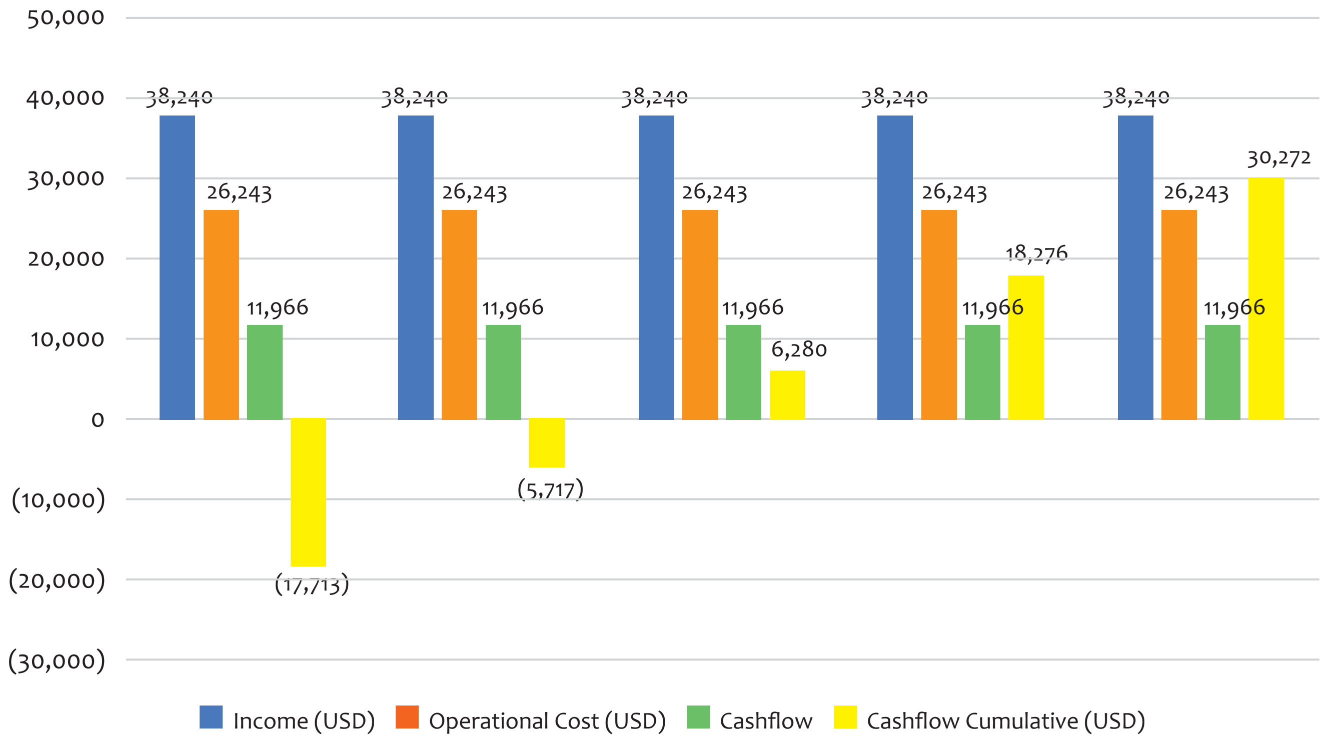

Figure 7 Income, Operational Cost, Cashflow, and Cashflow Cumulative Graph

CONCLUSION

There are three conclusions in this research: first, the results showed that the supply chain integration model and sorghum-based agri-farm process integration could provide certainty for a sustainable supply of animal silage feed. This research found a dynamic model of sustainable economic resilience in rural communities based on circular farming and an integrated supply chain, including the production of sorghum, silage, animal manure, and organic fertilizer, which formed a closed cycle requiring each other to achieve zero waste. By following the proper steps in the use of organic fertilizers, sorghum plants can grow well and provide optimal yields. Good organic fertilizer management not only provides economic benefits for farmers but also helps maintain the health of the environment and soil for a better future. Second, this agri-farm integration tends to generate additional sources of income for farmer groups, such as through the sale of sorghum seeds, goats, and manure. A potential gross profit of $11,996/year was generated through the agri-farm integration system from the sale of 13,590 Kg of sorghum grain for $4,530 at $0.33/kg, 300 goats/year for $33,600 ($4.67*24kg/goat), and 822 Kg of fertilizer for $110, while the operational costs for 1 ha were $26,243/year. Third, the income generated by integrated farming for 1 ha of land was $38,240/year, while operational costs were $26,243/year, leading to a total annual profit of $11,996/year. From the simulation and calculation results, it was found that the positive NPV in the third year was $124, with a company interest of 10%, the IRR value was10%, and the PBP was 2.48 years. These findings demonstrate that agri-farm integration models not only enhance rural economic resilience but also offer practical policy implications. The model presents a scalable framework for agricultural policy development that can be adapted and implemented in other rural regions with similar socio-agricultural contexts. Scaling this model could support national strategies for food security, rural empowerment, and climate-resilient agriculture, particularly in developing economies facing structural vulnerabilities in their agricultural supply chains. The limitations of this study include solely discussing the sustainable economic resilience of rural communities based on circular farming and an integrated supply chain, comprising the production of sorghum, silage, animal manure, and organic fertilizer, which formed a closed cycle to achieve zero waste. The development of economic resilience in rural communities was only identified as based on integrated agri-farms. Therefore, future research is techno-economic studies about derivative products obtained from sorghum plants, such as bioethanol and flour, to provide additional income to farmers. This study investigates how an integrated agri-farming process can contribute significantly to the economic sustainability of rural communities. Integration of agri-farm processes starts with the production of sorghum biomass as a raw material for silage, which is consumed by goats to become animal manure for processing into compost manure. These four processes form a closed cycle and can provide certainty of the raw materials in each production process. Through integrated agri-farming, potential profits from selling silage, sorghum grain, goats, and manure are large, thereby increasing the economic resilience of rural communities in an environmentally friendly and sustainable manner.

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