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MORALITY BEFORE KNOWLEDGE

Strengthening rural food security and community welfare through ICLS 5.0: A socio-biological approach to circular agriculture

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ABSTRACT
Background: Nutritional disparities remain a major challenge in Indonesia's human resource development, as the prevalence of stunting and wasting continues to vary widely across regions despite measurable national progress. These inequalities highlight the need for integrated and sustainable agricultural innovations that improve both food quality and availability while maintaining ecological balance. This study aims to analyze the potential of the Integrated Crop–Livestock System (ICLS) 5.0 as an innovation that strengthens food security and enhances nutritional value through sustainable resource management. **Method:** A quantitative descriptive approach based on a comprehensive literature review was conducted using secondary data from scientific journals and national databases. The ICLS 5.0 framework emphasizes circular resource use, converting agricultural residues such as rice straw, corn stalks, and dry leaves into fermented forage, while livestock manure is processed into organic fertilizer through bioactivation and composting. Data were analyzed to assess improvements in productivity, soil fertility, and resource efficiency. **Finding:** Implementation of the ICLS 5.0 model can increase agricultural and livestock productivity by 30–40%, enhance soil carbon and nitrogen content, and reduce production costs by 30–50% through the substitution of chemical fertilizers and industrial feed. The system also reduces greenhouse gas emissions and improves food self-sufficiency in rural areas by promoting local feed and fertilizer production. **Conclusion:** The ICLS 5.0 approach provides a low-cost, scalable, and knowledge-based innovation that aligns with national efforts to strengthen food and nutrition security. By integrating crops and livestock within a circular economy framework, this model supports sustainable agricultural intensification and contributes directly to achieving Sustainable Development Goals (SDG 2 Zero Hunger, SDG 12 Responsible Consumption and Production, and SDG 13 Climate Action), while enhancing the resilience and welfare of rural farming communities. **Novelty/Originality of this article:** This innovation introduces an adaptive crop–livestock integration model suitable for various land scales, complemented by a localized ICLS framework. It also provides simple technical guidelines for converting organic waste into fertilizer, feed, or energy, along with the development of micro-scale circular economy systems for farmer and livestock groups.

KEYWORDS: fermented forage; integrated crop–livestock system; livestock manure.

1. Introduction

Nutritional problems in Indonesia remain a serious challenge in efforts to develop human resources. The 2024 Indonesian Nutritional Status Survey recorded a decrease in stunting prevalence from 21.5% in 2023 to 19.8% in 2024. This decline is the cumulative

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result of multisectoral interventions since 2019, when the stunting rate was 27.7%, dropping to 24.4% by 2021. However, the reduction has not been evenly distributed. Several provinces still have much higher rates, such as East Nusa Tenggara (NTT) at around 37%, while Bali successfully reduced its rate to 8.7%, indicating that disparities in intervention and service access between regions still persist.

One of the most concerning nutritional issues in recent years is chronic malnutrition in the form of stunted growth among children. According to Indonesia's Basic Health Research/*Riset Kesehatan Dasar* (Riskesdas) in 2013, around 37% (nearly 9 million) of children under five suffered from stunting, and this figure rose to 44% (Djauhari, 2017). In addition to stunting, another serious nutritional issue still found in Indonesia is wasting. This condition can be observed when a child's body weight decreases significantly over time, falling well below the normal range. Data from the Indonesian Nutritional Status Survey shows that the prevalence of wasting among children under five in 2022 was 7.7%, higher than the national target of 7%. Some provinces such as Maluku, West Papua, and Central Sulawesi recorded rates exceeding 11%. Meanwhile, the indicator of underweight (low weight-for-age) also increased from 15.9% in 2023 to 16.8% in 2024. The incidence of wasting in Indonesia in 2018 was 10.2%, showing an increase from 9.5% in 2017. Several direct and indirect factors contribute to wasting (Sari, 2022). This condition is generally caused by various interrelated factors, including inadequate intake of balanced nutritious food, lack of nutritional knowledge, poverty, and poor environmental conditions. Globally, child malnutrition based on weight-for-age (W/A), height-for-age (H/A), and weight-for-height (W/H) indicators remains very high and poses a major health challenge, particularly in developing countries (Ramlah, 2021).

In response to these issues, the Indonesian government has demonstrated its commitment to strengthening the food and nutrition system through various regulations. One of these is Law No. 7 of 1996 on Food, which emphasizes the importance of fulfilling the nutritional needs of all citizens. This commitment was further reinforced through Government Regulation No. 28 of 2002 on Food Security, which states that ensuring food availability is a shared responsibility between the government and the community. Furthermore, food and nutrition security are classified as mandatory affairs in national development at both central and regional levels (Sutrisno, 2022).

The food security system in Indonesia is not merely defined by food availability but also includes aspects of accessibility, distribution, nutritional quality, and stability at the household level. Weaknesses in Indonesia's food security often arise due to limited purchasing power among low-income families, uneven food distribution, and low public awareness regarding the selection and preparation of nutritious food (Suryana, 2015). These conditions are exacerbated by non-economic factors such as monotonous dietary habits, poor parenting practices, and unsanitary environments that increase the risk of infections and worsen children's nutritional status (Amalia et al., 2022). Thus, the food security system becomes one of the main determinants of nutritional problems among young children, including the persistently high rate of stunting in Indonesia. Strengthening food security requires the involvement of multiple sectors from the government and health institutions to the community in improving food distribution and availability, increasing nutritional education, strengthening basic health services, and promoting healthier and more sustainable consumption behaviors (Risvenjaya et al., 2024).

Basically, Indonesia's food security system has several advantages that can serve as strategic assets in achieving national food self-sufficiency and progress. The availability of staple foods is relatively stable through domestic production, particularly rice, which continues to meet most of the population's needs, thereby reducing the potential for widespread food crises (Hapsari & Rudiarto, 2017). Moreover, Indonesia possesses a vast diversity of natural food sources, ranging from agricultural, plantation, fishery, to livestock products, which, if managed optimally, can strengthen local based food availability (Risvenjaya et al., 2024). Government support through programs such as government rice reserves, non-cash food assistance programs, and food diversification initiatives also demonstrates the state's commitment to maintaining food access, especially for vulnerable groups. Additionally, the adoption of modern agricultural technologies and biofortification research continues to enhance productivity and food quality in the future (Suryana, 2015).

Despite these strengths, Indonesia's food security system still faces major challenges that could threaten its sustainability and stability. External factors such as environmental changes, dependence on global market dynamics, and international geopolitical situations also affect national food vulnerability. One of the most critical issues is global climate change, which poses a serious threat to the livestock sector by causing droughts, floods, and extreme weather that reduce feed availability and increase disease risk, thereby weakening livestock productivity and food supply stability (Agbeja et al., 2021). Dependence on imported feed ingredients such as corn, soybeans, and rice further increases vulnerability to global market fluctuations, potentially triggering price surges and food shortages (Tranggono et al., 2023). This situation is worsened by fluctuations in international energy and transportation prices, which directly impact livestock production costs. Additionally, geopolitical conflicts such as the Russia and Ukraine war have demonstrated how disruptions in agricultural commodity exports and imports can hinder supply chains and cause unpredictable price spikes (Laber et al., 2023).

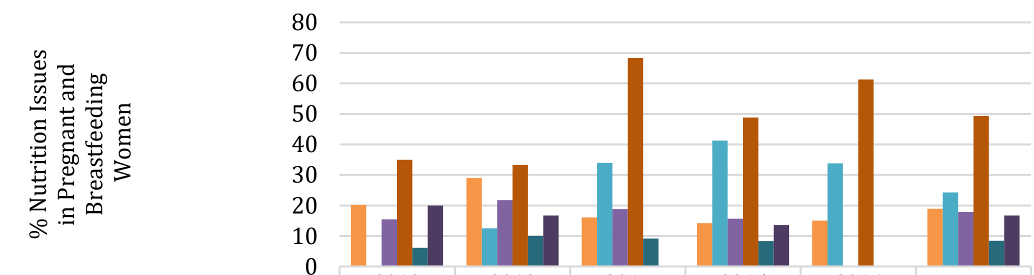
Improving agricultural productivity and strengthening national food security require strategic actions that emphasize reducing dependence on imported feed ingredients and promoting sustainable agricultural development. These efforts should be supported by appropriate government policies, such as providing incentives for farmers, developing environmentally friendly agricultural technologies, and promoting the consumption of local feed ingredients (Tranggono et al., 2023). Furthermore, implementing climate change adaptation strategies such as developing alternative feeds from agricultural waste and improving resource use efficiency has become increasingly relevant (Djauhari., 2017). In this context, the implementation of the Integrated Crop Livestock System (ICLS) plays a crucial role, as it integrates crop and livestock production within a mutually supportive system. This system not only enhances land-use efficiency and feed availability but also strengthens sustainability through organic waste management and soil fertility improvement, thereby contributing directly to long-term food security stability. Previous studies, such as Integrated Crop Livestock Systems as Circular Economy Strategies for Sustainable AgriFood Systems by Soares et al. (2024), emphasize the role of ICLS in supporting a circular economy by optimizing nutrient cycles, increasing carbon stocks, and contributing to climate change mitigation. However, the proposed implementation mainly focuses on large scale applications, such as integrating plantations with industrial livestock farming, making it less relevant to most Indonesian farmers who operate on small land areas (<0.5 ha) with limited livestock ownership.

Table 1. Identified limitations and required innovation directions

Aspect	Limitation of previous study	Required inovation direction
Implementation Scale	Focused on large-scale integration (industrial plantations and livestock farms).	Develop crop-livestock integration models suitable for small, medium, and large farmers with limited land (<0.5 ha) and livestock
Socioeconomic Context	Less relevant to the realities of small farmers in developing countries such as Indonesia.	Adapt ICLS frameworks to local contexts, limited resources, and smallholder capacities.
Technical Aspect	Lacks detailed technical descriptions of small-scale agricultural waste and manure processing.	Provide simple technical guidelines for converting organic waste into fertilizer, feed, or renewable energy at household or community levels.
Circular Economy Approach	Emphasizes macro-level concepts (nutrient cycles and carbon storage) without practical micro-level models.	Develop micro-scale circular economy systems applicable to local farmer groups or cooperatives.

Moreover, the study does not provide detailed technical descriptions of agricultural waste and manure management at the small-scale level, leaving a gap between the macro concept presented and practical needs in the field. This limitation highlights the need for new innovations focusing on small-scale or independent ICLS designs that can be adapted for large-scale use through simple, low cost, and practical approaches to support food security and sustainable agriculture among smallholder farmers. To highlight the gap between previous research findings and practical needs in the field, the following Table 1 summarizes the main limitations of Soares et al. (2024) and outlines potential innovation directions to make the ICLS concept more applicable for small to medium-scale farmers.

Integrated Crop-Livestock Systems (ICLS) are a form of regenerative agriculture that strategically combines crop cultivation and livestock production within the same land area to create synergistic interactions. In these systems, outputs from one component such as crop residues serve as inputs for the other, enhancing nutrient cycling, soil fertility, and overall farm productivity (Bueno et al., 2023). Integrated Crop-Livestock Systems (ICLS) have been proven to enhance farmers' productivity and income without causing adverse environmental impacts. In the context of climate change, this system demonstrates greater resilience compared to specialized agricultural systems, with significantly lower reductions in net revenue under extreme climate scenarios. The integration of crops and livestock allows for the efficient use of crop residues as animal feed and the application of livestock manure as organic fertilizer, thereby improving nutrient cycling and reducing dependence on synthetic inputs. Furthermore, ICLS offers additional income opportunities through the utilization of cover crops for grazing and the employment of draft animals to support agricultural activities. Thus, ICLS plays a vital role in achieving sustainable agricultural intensification and strengthening food security amidst the challenges of climate variability and limited resources.



	2012 (n125)	2013 (n100)	2014 (n112)	2015 (160)	2016 (n80)	Total
Poor nutritional status before pregnancy	20.2	29	16.1	14.2	15	18.9
Overweight/Obese Status Before Pregnancy	0	12.5	33.9	41.3	33.8	24.3
Risk of Chronic Energy Deficiency in Pregnant Women (a)	15.4	21.7	18.8	15.7	0	17.9
Weight gain < recommended (b)	35	33.3	68.3	48.8	61.3	49.3
Nutritional status of breastfeeding mothers (c)	6.1	10	9.2	8.3	0	8.4
Risk of chronic energy deficiency in breastfeeding mothers (d)	20	16.7	0	13.6	0	16.7

Fig. 1. Percentage of wasting and stunting
(Sari, 2022)

Understanding the implementation of the Integrated Crop Livestock System (ICLS) 5.0 is crucial for assessing how this innovation optimizes the use of livestock manure to enhance nutritional value and support sustainable food security. Through the integration of crops and livestock production, ICLS 5.0 enables more efficient recycling of organic residues, reducing waste and improving soil fertility while simultaneously increasing the availability of nutrient-rich agricultural outputs. Examining this system also provides valuable insights into how resource utilization in the agriculture and livestock sectors has shifted before and after its adoption, particularly in terms of input efficiency, cost reduction, and the sustainability of production processes. By analyzing these aspects, the study aims to elucidate the extent to which ICLS 5.0 contributes to better resource management and improved food system resilience.

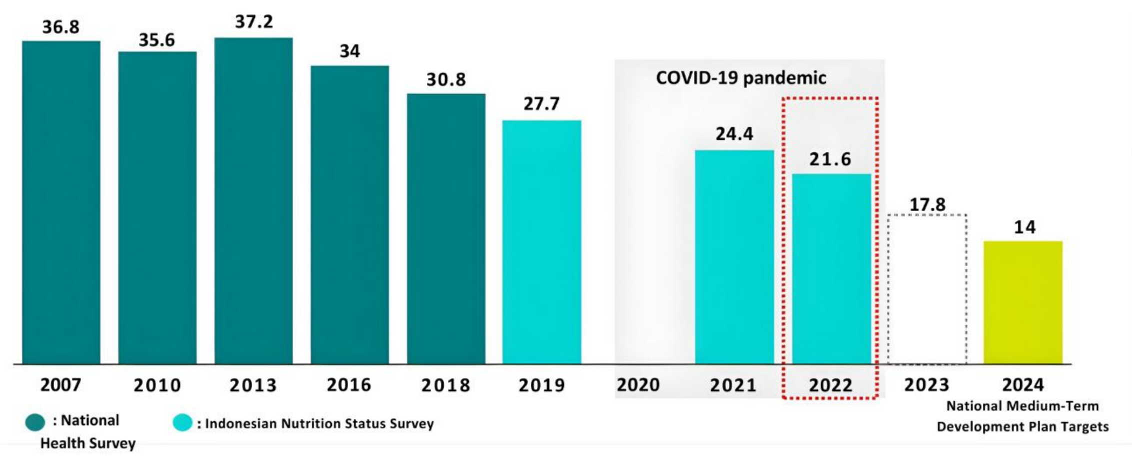


Fig. 2. Trends in stunting prevalence rate (2007-2022), projections (2023), and targets (2024) (Barokah & Soetono, 2024)

The objectives of this experiment are to examine how the implementation of the Integrated Crop Livestock System (ICLS) 5.0 contributes to optimizing the utilization of livestock manure to improve nutritional value and promote sustainable food security, and to evaluate the effectiveness of resource utilization in the agricultural and livestock sectors. before and after the implementation of the ICLS 5.0 system. Therefore, the implementation of the Integrated Crop Livestock System (ICLS) 5.0 based on the processing of livestock manure and fermented forage is expected to significantly enhance food security and nutritional quality through the establishment of a closed and sustainable crop livestock production cycle. The integration of agricultural residues into fermented feed is believed to reduce farmers' dependence on commercial feed, while the processing of livestock manure into organic fertilizer is hypothesized to improve soil fertility and decrease the use of synthetic chemical fertilizers. Consequently, the ICLS 5.0 system is predicted not only to increase the productivity of both crops and livestock but also to strengthen the stability of nutrient-rich food supply, reduce production costs, and contribute to sustainable development goals through the reduction of organic waste and carbon emissions. Overall, it is hypothesized that the implementation of ICLS 5.0 can serve as an effective strategy for achieving sustainable food security, particularly within small to medium scale agricultural and livestock systems.

2. Methods

2.1 Data collection method

The data collection method in this study employed a quantitative descriptive approach based on literature review and secondary data, without conducting direct field observations. The data used were obtained from various reliable sources such as scientific journals, research reports, and official publications discussing the Integrated Crop–Livestock Systems (ICLS). This approach aims to describe the functional relationship between agricultural and livestock components within a sustainable circular economy framework by utilizing available quantitative data, such as soil carbon content, nitrogen retention, livestock productivity, and land-use efficiency. This method was chosen because it can provide an objective overview based on verified data, without the need for experimentation or primary data collection in the field.

The data collection process was carried out through an extensive review of relevant scientific literature to obtain numerical data and previous analytical results that support this study. These data were then processed and analyzed using a quantitative descriptive method to explain the performance of the ICLS from various aspects, such as improvement of soil fertility, resource use efficiency, and contribution to carbon emission reduction. In addition, the analysis included comparative studies among research findings to evaluate the effectiveness of crop–livestock integration in enhancing agricultural system sustainability. Through this approach, the study provides a comprehensive understanding of the benefits and potential application of the ICLS without the need for direct observation, yet still grounded in valid and measurable scientific evidence.

2.2 Data presentation method

The data presentation method in this study employed the use of tables and bar charts to display the results of the literature analysis in a systematic and easily understandable manner. The data obtained from various secondary sources, such as scientific journals and research reports related to ICLS, were organized into tables containing the main quantitative variables, including soil carbon content, nitrogen retention efficiency, compost yield, fertilizer substitution rate, and the increase in crop and livestock productivity. Presentation in tabular form aims to provide a comprehensive comparison of results across studies, thereby facilitating the analysis of the relationship between crop–livestock integration and agricultural sustainability indicators.

In addition to tables, the data were also visualized using bar charts to illustrate trends and differences in the values of relevant variables. The bar charts were used to show proportional comparisons, such as the increase in soil organic matter content before and after the implementation of the ICLS system, the comparison of crop yields between conventional and integrated systems, and the percentage reduction in chemical fertilizer use. This visualization simplifies result interpretation by effectively displaying data trends quantitatively and clarifying the positive impacts of crop–livestock integration on land productivity and resource efficiency. By combining tables and bar charts, this data presentation method provides a clear, measurable, and communicative representation of the literature analysis results concerning the effectiveness of ICLS 5.0 implementation on the economic, environmental, and social aspects of sustainable agriculture.

2.3 Data analysis method

The data analysis method in this study employed a mixed-method approach, combining quantitative descriptive and qualitative interpretative methods to obtain a more comprehensive and in-depth analysis. The quantitative analysis was conducted by processing numerical data obtained from various secondary sources such as scientific journals, research reports, and academic publications relevant to the topic of Integrated Crop–Livestock Systems (ICLS) 5.0. The analyzed data included key variables such as soil carbon and nitrogen content, compost yield, nutrient retention efficiency, crop and livestock productivity, and the level of chemical fertilizer substitution. This quantitative approach was used to identify patterns, trends, and relationships among variables through comparisons of averages and percentages from multiple studies, providing an objective overview of the effectiveness of the ICLS system in improving sustainable agricultural performance.

Meanwhile, the qualitative analysis was carried out to interpret research findings related to the social, economic, and environmental aspects of ICLS implementation. Qualitative data was obtained through an in-depth literature review and analyzed using content analysis and thematic interpretation techniques to identify key themes such as resource efficiency, improvement of soil fertility, reduction of agricultural waste, and contributions to food security. This analysis also included an assessment of the roles of stakeholders, such as farmers, government institutions, and the private sector, in supporting the implementation of crop–livestock integration systems. By combining these two approaches, the study was able to produce an analysis that not only presents measurable quantitative data but also provides contextual and meaningful qualitative insights, offering a holistic and multidimensional understanding of the contribution of ICLS 5.0 to sustainable agricultural development.

2.4 Tools and materials

2.4.1 Tools

A cutting tool or chopper is used to cut the rice straw into lengths of 5–10 cm, which is important to ensure that the particle size is small enough to accelerate microbial penetration and maintain mixture homogeneity. Without cutting, the coarse structure of the straw will slow down the fermentation process and reduce silage quality. Storage containers such as plastic drums or simple silos that are airtight or at least tightly sealed are essential for creating the anaerobic conditions required for silage fermentation and for preventing oxidation, aerobic spoilage, or the growth of undesirable microorganisms.

A tarpaulin or cover is used to cover the compost or silage pile to maintain internal conditions (moisture and temperature) and to prevent direct rainfall or excessive evaporation, while tools such as rakes or manual mixers are used to turn the pile every three days to maintain aeration and ensure uniform decomposition. In the study entitled "Multi-Component Composting of Agricultural By-Products Improves Compost Quality and Effects on the Growth and Yield of Cucumber", it was shown that periodic turning of the compost pile is crucial for controlling temperature, microbial distribution, and the uniformity of decomposition (Thu & Loan, 2024).

2.4.2 Materials

Fresh or dried rice straw serves as the main material for silage; this straw provides a source of crude fiber that can be fermented into animal feed, although its low soluble sugar content requires special treatment. In the study "Characteristics of fresh rice straw silage quality prepared with addition of lactic acid bacteria and crude cellulase", it was explained that rice straw supplemented with lactic acid bacteria inoculant and cellulase enzyme experienced a decrease in pH and an increase in the rate of fermentation (Sarwono et al., 2022). The EM4 solution combined with molasses acts as a sugar additive; molasses provides soluble carbohydrates as an energy source for fermentative microbes, thereby helping to lower pH and improve stability. In the study "Effects of sugar sources and doses on fermentation dynamics, carbohydrates changes, in vitro digestibility and gas production of rice straw silage", it was shown that the use of molasses in rice straw silage affects fermentation dynamics (Zhao et al., 2019).

2.5 Research procedure

2.5.1 Phase I: Fermented forage production

Technically, agricultural waste in the form of rice straw, with an average production of 3–5 tons per hectare per season, can be processed into animal feed through the silage process. The straw is cut into lengths of 5–10 cm, then fermented with a solution consisting of 1 liter of EM4 and 5 tablespoons of molasses for every 10 kg of straw. The material is stored in plastic drums or simple silos for 14–21 days until it produces feed with a fresh acidic aroma that is more durable and easily digestible by livestock.

This silage feed can reduce dependence on manufactured feed while supporting an integrated crop–livestock system that has been proven to increase soil carbon and nitrogen reserves as well as more stable soil organic matter fractions (Soares et al., 2024). Furthermore, in the journal "The Use of Integrated Crop Livestock Systems as a Strategy to Improve Soil Organic Matter in the Brazilian Cerrado", it was proven that the integrated crop–livestock system could increase soil carbon reserves up to 72.8 Mg ha^{-1} and nitrogen 5.5 Mg ha^{-1}, indicating that the practice of utilizing rice straw as silage aligns with strategies to enhance the sustainability of agricultural ecosystems in tropical lands (Soares et al., 2024).

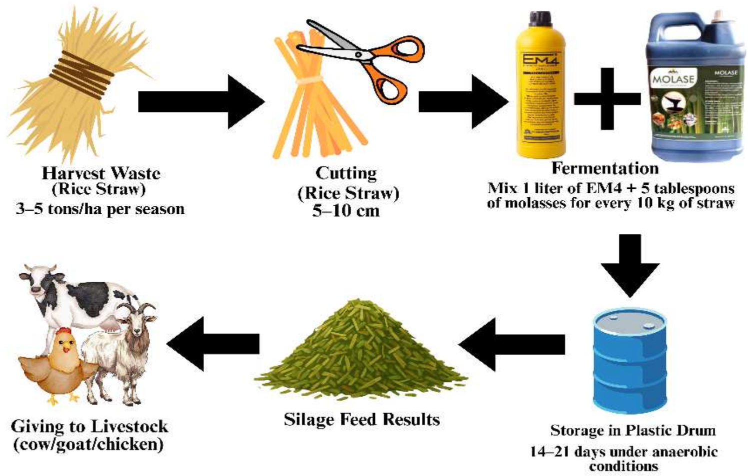


Fig. 3. Fermented forage production flow

2.5.2 *Phase II: Livestock manure composting*

The livestock then produces manure that is reused as organic fertilizer. In an integrated crop–livestock system, livestock manure plays an important role in returning nutrients to the soil and increasing organic carbon content, thereby maintaining soil fertility sustainably (Werner et al., 2024). An adult cow, for instance, can produce 15–20 kg of fresh manure per day. The manure is fermented with carbon materials such as rice husks or dry straw and supplemented with bran at a ratio of 10:3:1. Next, an EM4 solution is added at 10 mL per liter of water until the moisture content of the mixture reaches 40–60%, indicated by a texture that clumps when squeezed but does not release water.

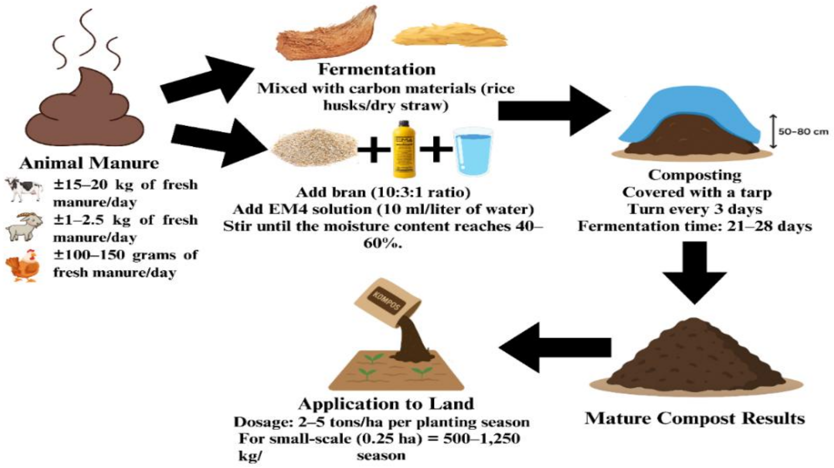


Fig. 4. Livestock manure composting flow

The pile, with a height of 50–80 cm, is then covered with a tarp and turned every three days. Within 21–28 days, the livestock manure transforms into mature compost that is dark brown in color, crumbly in texture, and has a fresh earthy smell. The resulting organic fertilizer is applied to agricultural land at an average rate of 2–5 tons per hectare per planting season, which can replace 30–50% of the chemical fertilizer requirement. For a smaller scale, such as 0.25 hectares, the required amount of organic fertilizer is only about 500–1,250 kg per season, an amount that can be supplied by 2–3 cows within one month.

3. Results and Discussion

3.1 Research site and location

This study was conducted in various regions across Indonesia, encompassing the western, central, and eastern parts of the country, to illustrate the diversity in the implementation of Integrated Crop–Livestock Systems (ICLS) across different agroecosystems. The research sites were selected based on the diversity of agroclimatic conditions, the availability of agricultural resources, and the patterns of crop–livestock integration in each region. The western region of Indonesia, which includes Sumatra, Java, and Bali, is characterized by high agricultural intensification and relatively advanced infrastructure and technology (Widarni et al., 2020).

In this region, integration crop–livestock systems are commonly implemented in the forms of rice–cattle, maize–goat, and sugarcane–cattle systems, where crop residues or by-products are utilized as animal feed, while livestock manure is used as organic fertilizer. This practice demonstrates efficient resource utilization and supports increased land productivity. However, urbanization dynamics and land ownership fragmentation in this area often limit agricultural space and reduce the sustainability of integrative practices.

3.2 Implementation of the integrated crop-livestock farming system (ICLS) in Indonesia

3.2.1 Implementation of ICLS in western Indonesia

The implementation of the Integrated Crop–Livestock Systems (ICLS) in the western region of Indonesia has shown positive outcomes in improving agricultural efficiency and sustainability. One of the most well-documented applications is the Rice Livestock Integration System program in Gunung Kidul Regency, Yogyakarta Special Region, as studied by Widadie & Agustono (2015) in their research titled Comparison of Integrated Crop–Livestock and Non-Integrated Farming Systems for Financial Feasibility, Technical Efficiency, and Adoption. The study compared two groups of farmers, those who applied the integrated crop–livestock system (ICLS) and those who did not (non-ICLS). The analysis covered socioeconomic, technical, and financial aspects, as well as the factors influencing the adoption of the system at the farmer level (Widadie & Agustono, 2015).

Based on Table 2, the research findings indicate that farmers implementing the Integrated Crop–Livestock System have consistently better socioeconomic conditions compared to non-ICLS farmers. Livestock ownership stands out as the most significant indicator; ICLS farmers own an average of 1.84 head of cattle per household, nearly twice as many as non-ICLS farmers, who own only 0.97 head. The allocation of family labor for livestock maintenance is also considerably higher, at 61.45 hours per week compared to 31.52 hours in non-integrated systems. In addition, ICLS farmers are more actively involved in agricultural extension and training activities. The frequency of contact with extension workers was recorded at 0.56 times per year, higher than that of non-ICLS farmers (0.39 times per year). Most ICLS farmers (63%) had participated in specialized training on crop–livestock integration, while only about 31% of non-ICLS farmers had done so. This condition underscores that human resource capacity and institutional support play crucial roles in the successful adoption of integrated farming systems (Widadie & Agustono, 2015).

From an economic perspective, the ICLS system has been proven to provide higher financial benefits compared to non-integrated systems. Rice productivity increased significantly from 10.08 quintals to 13.88 quintals per hectare, while cassava yield rose from 5.58 to 7.68 quintals. This increase in yield is directly related to the use of livestock manure as fertilizer, which improves soil structure and fertility while reducing dependence on chemical fertilizers. The total gross income of ICLS farmers reached IDR 34 million per hectare per planting season, about 27% higher than that of non-ICLS farmers, who earned only IDR 11.28 million. Although the fixed and variable costs were nearly the same (around IDR 3.9 million), the net income of ICLS farmers was substantially higher IDR 10.34 million compared to IDR 7.36 million in non-integrated systems. The Benefit–Cost Ratio (B/C) was also slightly higher for ICLS sebanyak 3.39 than for non-ICLS 3.35, indicating that ICLS-based farming activities are more efficient and economically profitable. This income difference was statistically significant at the 1% confidence level ($p < 0.01$), suggesting that crop–livestock integration genuinely contributes to improving farmers' welfare (Widadie & Agustono, 2015).

Table 2. Comparison of livestock and crop farming using the ICLS system in western Indonesia

Aspect	Variable / Indicator	ICLS (Adopters)	Non-ICLS(Non-Adopters)
Social-Economic	Agricultural income (IDR million/year)	10.34 ± 4.08	7.35 ± 3.13
	Land area (m^2)	5,231.61 ± 3,102.8	5,091.9 ± 2,939.7
	Number of cattle (head)	1.84 ± 1.2	0.97 ± 0.98
	Family labor for livestock (hours/week)	61.45 ± 72.08	31.52 ± 44.84
	Frequency of contact with extension workers	0.56 ± 0.49	0.39 ± 0.48
Financial	Rice yield (quintals)	13.88	10.08
	Maize yield (quintals)	7.37	7.64
	Groundnut yield (quintals)	2.80	2.20
	Cassava yield (quintals)	7.68	5.58
	Total gross income (IDR)	14,346,780	11,287,574
	Average fixed cost (IDR)	1,701,840	1,539,461
	Average variable cost (IDR)	2,200,443	2,388,604
	Net income (IDR)	10,344,496	7,359,507
	B/C ratio	3.39	3.35
Technical Efficiency	Mean technical efficiency	0.791 ± 0.117	0.677 ± 0.149
	Minimum	0.412	0.293
	Maximum	0.981	0.919
	Efficiency distribution 0.7–0.9	55.38%	44.68%
	Efficiency distribution < 0.6	12.31%	29.79%

(Widadie & Agustono, 2015)

The analysis of technical efficiency using the Stochastic Frontier Analysis (SFA) approach showed that farmers implementing the Integrated Crop–Livestock System (ICLS) achieved an average efficiency level of 0.791, while non-integrated farmers reached only 0.677**.** This indicates that farmers under the integrated system have achieved about 79% of the maximum potential output attainable with the same combination of inputs, whereas non-integrated farmers have reached only around 68%. Most ICLS farmers approximately 55% fell into the high-efficiency category, with efficiency scores ranging from 0.7 to 0.9, while non-integrated farmers were predominantly in the medium to low-efficiency range of 0.5 to 0.7. The variation in efficiency among ICLS farmers was also smaller, with a standard deviation of 0.117 compared to 0.149 for non-ICLS farmers. This suggests that cultivation practices within the integrated system are applied more uniformly and efficiently (Widadie & Agustono, 2015).

3.2.2 Implementation of ICLS in central Indonesia

The implementation of the integrated crop–livestock farming system in the central region of Indonesia, particularly in West Kalimantan, has developed as a strategy for sustainable peatland management. A study conducted by Widiastuti et al. (2024), titled Peatlands Management for Sustainable Use on the Integration of Maize and Cattle in a Circular Agriculture System in West Kalimantan, Indonesia, showed that the integration of maize and cattle can increase agricultural productivity while improving environmental quality through the principles of circular agriculture. This system utilizes agricultural waste as animal feed and livestock manure as organic fertilizer, creating a closed, efficient, and environmentally friendly cycle. The integration model was implemented on peatlands in Kubu Raya Regency, where farmers had previously relied on monoculture systems with limited yields and income. After the application of ICLS, there was a significant increase in crop yields, household income, and input-use efficiency. The integration also successfully reduced carbon dioxide emissions on peatlands, which had previously been high due to organic degradation and open burning (Widiastuti et al., 2024).

Table 3. Comparison of livestock and crop farming using the ICLS system central Indonesia

Aspect	Variable / Indicator	ICLS (Adopters)	Non-ICLS(Non-Adopters)
Socio-Economic	Average household income (IDR/month)	High	Low
	Family labor involvement	Integrated maize–cattle	Monoculture maize
	Farming pattern	8.24	5.06
Production	Maize yield (Sukmaraga variety, tons/ha)	8.25	5.27
	Maize yield (Bisi 22 variety, tons/ha)	Used as cattle feed (silage)	Not utilized
	Maize residue utilization	≈200 L/head/month	Not available
Livestock & Environment	Organic fertilizer and biourine production	7.84	12.04
	CO_2 emission from peatlands (tons/ha)	4.06	3.12
	Soil organic carbon (%)	1.01–1.44	0.87–0.95
Financial Feasibility	R/C Ratio	High	Low
	Input efficiency	Circular agriculture system	Non-integrated
	Sustainability scheme	14,600,000	4,760,000

(Widiastuti et al., 2024)

Based on Table 3, farmers who implemented the integrated maize–cattle farming system (ICLS) in West Kalimantan showed much better socioeconomic conditions compared to those who still used conventional or monoculture systems. Before the implementation of ICLS, the average household income of farmers was only IDR 4,760,000 per month, whereas after applying the integrated system, it sharply increased to IDR 14,600,000 per month, an increase of more than 200%. This improvement indicates that the ICLS system can provide significant economic benefits through the diversification of income sources, where farmers gain profits not only from maize production but also from utilizing livestock waste as marketable organic fertilizer (Widiastuti et al., 2024).

In addition, family labor participation among ICLS farmers increased substantially compared to those in non-integrated systems. Additional activities such as cattle maintenance, preparation of fermented feed, and compost processing were carried out at the household level, which indirectly created new job opportunities and strengthened the family's economic role. This condition demonstrates that the implementation of the integrated farming system contributes to reducing hidden unemployment in rural areas and enhancing the economic resilience of farming communities (Widiastuti et al., 2024).

In terms of productivity, farmers who implemented the integrated maize–cattle farming system or 'ICLS showed significantly higher yields compared to those who continued managing their land under non-integrated systems. The productivity of the Sukmaraga maize variety increased from 5.06 tons per hectare in conventional systems to 8.24 tons per hectare after the implementation of ICLS, while the Bisi 22 variety rose from 5.27 tons per hectare to 8.25 tons per hectare. This yield increase of more than 55 percent demonstrates that the application of ICLS effectively improves soil fertility and input-use efficiency through the use of organic fertilizer derived from livestock waste and the availability of high-quality silage feed made from maize residues (Widiastuti et al., 2024). In addition to increasing crop yields, the integrated system also promotes the utilization of crop residues that were previously discarded. Maize residues, such as stalks and leaves, are processed into fermented livestock feed, thereby eliminating the practice of open-field burning commonly found in non-integrated systems. This condition not only reduces environmental pollution but also strengthens the sustainable cycle of local resource utilization (Widiastuti et al., 2024).

The positive impact of implementing the ICLS system is also evident in the environmental aspect, particularly in reducing peatland degradation. The production of manure and biourine reached approximately 200 liters per head per month, which was utilized as organic ameliorants to improve soil structure. As a result, carbon dioxide emissions from peatlands decreased by 34.92 percent, from 12.04 tons/ha to 7.84 tons/ha, while the soil organic carbon content increased by 30.13 percent, from 3.12% to 4.06%. These results indicate that the nutrient cycle within the integrated system can improve soil quality while enhancing carbon sequestration, in line with the principles of climate-smart agriculture in tropical peatland ecosystems (Widiastuti et al., 2024). The economic feasibility analysis based on the R/C ratio shows a significant shift from an unfeasible to a financially feasible condition. Before the implementation of ICLS, the R/C value ranged only between 0.87 and 0.95, indicating relatively low profitability. After the integration was applied, the R/C value increased to 1.01–1.44, proving that the system is economically profitable. The reduced dependence on chemical fertilizers and the optimization of agricultural waste recycling lowered overall input costs. The implementation of the circular agriculture concept also ensures long-term sustainability through a zero-waste system and efficient carbon management.

3.2.3 Implementation of ICLS in eastern Indonesia

The implementation of the Integrated Crop–Livestock Systems (ICLS) in Eastern Indonesia has begun to develop as a strategic approach to improving the efficiency of the agricultural, livestock, and fisheries sectors in an integrated manner. One of the key studies on this matter was conducted by Daud et al. (2023) in a research titled Analysis of the Potential Integrated Agricultural Sector in North Maluku Province, which examined the potential for inter-subsector integration in North Maluku Province. The study explores how integrated agricultural systems can serve as a solution to strengthen food security and promote rural development in Eastern Indonesia, a region characterized by its archipelagic geography and limited land resources. Through sectoral analysis and the Location Quotient (LQ) approach, the study highlights the interconnections among the food crop, plantation, livestock, and fisheries subsectors as the foundation for implementing ICLS at the regional level (Daud et al., 2023).

Based on Table 4, the implementation of the integrated agricultural system in North Maluku shows a significant shift in the economic structure of farming households. Prior to integration, most farmers operated at a subsistence level with an average monthly income below IDR 2,500,000, relying primarily on a single commodity such as rice or maize. After the development of the Integrated Crop–Livestock System based on crop–livestock–fishery diversification, income potential increased to IDR 3,500,000–IDR 5,000,000 per month. This improvement is attributed to higher productivity and the emergence of new sources of income from by-products such as organic fertilizers, fermented feed, and locally processed products. In addition to the economic improvement, integration among subsectors has also strengthened rural labor participation. Previously, agricultural activities in North Maluku tended to be seasonal, employing labor only during planting or harvesting periods. However, through ICLS, activities such as livestock maintenance, compost production, and product processing have created year-round employment opportunities. Farmers' involvement in integration-based cooperatives has also increased, fostering social solidarity and strengthening interregional economic networks (Daud et al., 2023).

Table 4. Comparison of livestock and crop farming using the ICLS system eastern Indonesia

Aspect	Variable/Indicator	ICLS (Adopters)	Non-ICLS(Non-Adopters)
Socio-Economic	Farmers' income (IDR/month)	IDR 3,500,000–5,000,000	< IDR 2,500,000 (subsistence level)
	Employment absorption	Multi-sector employment (crop, livestock, processing)	Dominated by crop farming (seasonal)
	Farmer participation	Strengthened through cooperative-based integration	Low and fragmented by subsector
Agricultural Production	Main crops	Integrated with livestock (feed and manure use)	Separated: rice, corn, cassava
	Livestock integration	Integrated cattle–goat–poultry systems	Limited and unplanned
	Plantation and fisheries linkage	Combined agroforestry–fishpond–livestock schemes	Operated independently
Environmental Sustainability	Land use and management	Optimized through land–water–livestock synergy	Fragmented; expansion into marginal land
	Soil and water quality	Improved by organic fertilizer and mixed farming	Degrading due to monoculture and erosion
	Waste management	Recycled for compost and biogas	Agricultural and livestock waste unmanaged
Institutional and Policy Support	Regional programs	Provincial 'Integrated Agricultural Sector' policy initiative	Limited to crop intensification
	Stakeholder involvement	Multi-actor participation (government, cooperatives, academia)	Mostly local farmers and small traders
Economic Feasibility	Sector contribution to GRDP	Potential combined >40% with full integration	Agriculture 28%, livestock 8% (separate)
	Production stability	Year-round production through diversification	Seasonal fluctuation

(Daud et al., 2023)

From the production perspective, the agricultural system in North Maluku was previously still sectoral, where food crops, livestock, and fisheries were managed separately without a clear input–output relationship. The implementation of ICLS enables the use of agricultural waste as livestock feed and the utilization of animal manure as organic fertilizer, which improves soil fertility and input efficiency. As a result, agricultural land productivity has increased, particularly for commodities such as maize, rice, and tubers, while yield stability has also improved even during the dry season (Daud et al., 2023). Integration has also been expanded into the plantation and fishery sectors through the development of agroforestry models that combine perennial crops, fishponds, and livestock grazing areas. This approach not only enhances the overall productivity of the system but also strengthens local food security by producing food, animal protein, and biomass energy within a single integrated production area (Daud et al., 2023).

From the environmental and sustainability aspects, prior to the implementation of ICLS, agricultural expansion in North Maluku largely occurred in marginal and sloped areas, leading to soil degradation and erosion. Through the integrated system, land-use patterns are optimized based on ecosystem carrying capacity, utilizing the interactions between crops, water, and livestock to maintain soil fertility and moisture. In addition, the application of organic fertilizers derived from livestock waste helps increase soil organic matter content and reduce the previously high dependence on chemical fertilizers (Daud et al., 2023). The environmental aspect is also strengthened through waste management. Whereas agricultural and livestock waste had previously gone unused, most of it is now processed into compost and biogas, creating an environmentally friendly circular resource flow. This approach aligns with the Sustainable Development Goals (SDGs) for efficient and sustainable natural resource management (Daud et al., 2023).

3.3 The impact of ICLS implementation on nutrition improvement

Implementation of the Integrated Crop–Livestock System (ICLS) in various regions of Indonesia has shown a significant contribution to improving household nutritional quality and strengthening sustainable food security. This system integrates food crops, livestock, and local resources within a complementary production cycle, thereby providing nutritious food while maintaining ecological balance and agricultural economic efficiency. The increase in energy and protein intake across various regions of Indonesia can be observed in Table 5.

Table 5. Increase in energy and protein intake in Indonesian provinces over the past 3 years (2022–2024)

Province	Calories (Kcal)			Proteins (gram)		
	2022	2023	2024	2022	2023	2024
Aceh	2,064.30	2,052.85	1,989.55	61.17	61.05	60.64
North Sumatra	2,123.41	2,093.67	2,041.63	64.65	62.91	62.11
West Sumatra	2,109.43	2,086.06	2,032.94	59.24	58.68	57.79
Riau	2,022.05	2,048.04	2,017,10	59.69	59.97	59.16
Jambi	2,069.51	2,042.69	2,011.88	60.70	59.52	58.73
South Sumatra	2,182.47	2,191.06	2,196.16	65.18	65.10	66.43
Bengkulu	2,037.55	2,059.98	2,032.04	60.29	60.32	60.58
Lampung	2,002.72	2,096.21	2,005.80	57.67	60.13	57.99
Bangka Belitung Islands	2,065.86	2,058.61	1,992.17	67.57	66.38	65.69
Riau islands	2,019.87	2,047.79	2,050.02	64.67	66.50	67.05
Jakarta Special Capital Region	2,146.87	2,157.83	2,173.28	68.15	70.65	68.15
West Java	2,115.70	2,110.33	2,069.91	63.62	63.44	62.26
Central Java	2,017.64	2,024.95	1,993.03	59.78	59.65	59.23
Special Region of Yogyakarta	2,024.44	2,052.77	2,015.51	62.65	63.78	62.32
East Java	2,041.69	2,068.37	2,046.20	59.96	60.66	60.48
Banten	2,270.48	2,207.37	2,184.28	69.31	66.93	66.03
Bali	2,145.71	2,263.58	2,295.02	61.37	65.86	67.22
West Nusa Tenggara	2,460.44	2,484.92	2,419.21	74.82	76.12	74.45
East Nusa Tenggara	1,974.12	1,938.18	1,930.43	56.36	54.54	55.06
West Kalimantan	1,892.26	1,919.50	1,903.38	58.19	58.63	58.52
Central Kalimantan	2,116.05	2,133.87	2,050.60	65.01	64.01	61.84
South Kalimantan	2,188.80	2,167.47	2,198.30	68.01	67.36	69.20
East Kalimantan	1,918.34	2,008,81	1,960.46	63.00	65.72	64.30
North Kalimantan	1,857.92	1,891.28	1,869.58	59.74	62.11	61.69
North Sulawesi	2,154.56	2,104.76	2,011.68	68.06	65.22	63.62
Central Sulawesi	2,001.12	2,055.42	2,042.80	58.12	59.04	60.58
South Sulawesi	2,077.92	2,110.28	2,073.99	64.18	64.14	64.63
Southeast Sulawesi	1,948.63	2,019.29	1,955.09	60.39	61.37	60.98
Gorontalo	1,958.11	1,996.25	1,938.17	57.10	58.46	59.12
West Sulawesi	2,082.99	2,099.73	2,068.70	61.40	59.94	60.03
Maluku	1,836.68	1,819.57	1,791.94	52.91	52.86	52.20
North Maluku	1,843.68	1,822.80	1,800.54	54.76	52.70	52.05
West Papua	1,879.75	1,859.62	1,769.80	55.32	54.62	51.78
Southwest Papua	-	-	1,890.36	-	-	57.83
Papua	1,902.04	1,902.72	1,792.90	45.07	46.80	54.73
South Papua	-	-	1,790.62	-	-	51.57
Central Papua	-	-	1,696.02	-	-	43.48
Papua Mountains	-	-	2,190.07	-	-	39.89
Indonesia	2,079.09	2,087.64	2,095.54	62.21	62.33	63.70

(Badan Pusat Statistik, 2024)

The data show that the average per capita consumption of energy and protein experienced positive fluctuations during the 2022–2024 period, particularly in provinces that have begun adopting the Integrated Crop–Livestock Systems (ICLS). Based on data from the Central Bureau of Statistics (Badan Pusat Statistik, 2024) in Table 5, the pattern of energy and protein consumption of the Indonesian population shows a consistent increasing trend from 2022 to 2024 in almost all provinces. The implementation of the Integrated Crop–Livestock Systems (ICLS) in various regions of Indonesia shows a real impact on the improvement of community energy and protein intake. This increase shows a real improvement in the availability and consumption of nutritious food by farmer households, driven by the increase of local agricultural productivity and the availability of food products from the integrated system.

The implementation of this system encourages the efficiency of local resource utilization and improves access to nutritious food, especially in rural areas that previously faced limited food availability. The trend of energy and protein consumption shows a consistent increase from year to year, indicating an improvement in the nutritional quality of the community in line with the implementation of the integrated agricultural system. The implementation of Integrated Crop–Livestock Systems also plays an important role in building a sustainable agricultural cycle through the optimization of energy and material flows within the production system. In this approach, crop residues are utilized as livestock feed, while livestock waste, including manure and urine, is processed into organic fertilizer that is returned to agricultural land. This biomass recycling mechanism not only enhances soil fertility and organic matter content but also contributes to the sustainable improvement of food crop productivity (Domínguez-Hernández et al., 2025).

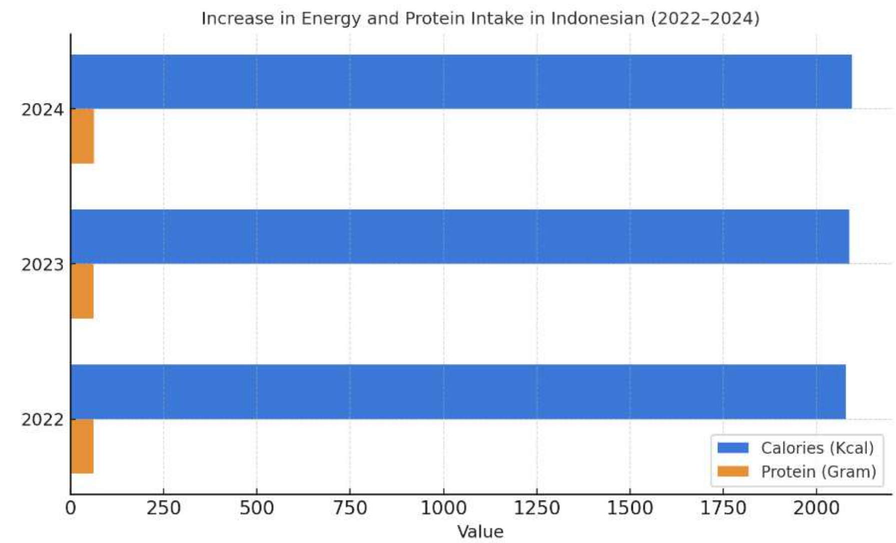


Fig. 5. Increase in energy and protein intake in Indonesian (2022-2024)

The Figure 5 shows an increase in the average energy and protein intake of the Indonesian population during the 2022–2024 period, which coincides with the wider implementation of the Integrated Crop–Livestock Systems across various regions. Energy intake increased from 2,079.09 kcal in 2022 to 2,095.54 kcal in 2024, while protein intake rose from 62.21 grams to 63.70 grams per capita per day. This increase indicates a tangible improvement in the availability of nutritious food and protein consumption, largely driven by the efficiency of integrated agricultural production systems. The implementation of ICLS plays an important role in improving agricultural productivity through crop–livestock rotation and diversification, which provides sustainable livestock feed and food sources throughout the seasons (Werner et al., 2024).

The application of ICLS also contributes to enhancing food security through the utilization of agricultural waste as livestock feed and the processing of livestock manure into organic fertilizer. This circular system strengthens the relationship between crop and livestock sectors, creating input efficiency and improving soil quality. The integration between crops and livestock enables the use of agricultural residues such as rice straw, corn stalks, and pods as high-quality animal feed, while livestock waste is processed into organic fertilizer that improves soil structure and fertility. Thus, the ICLS concept directly supports

SDG 2: Zero Hunger by increasing food availability and sustainability (Werner et al., 2024). In addition to increasing food productivity, the implementation of ICLS also supports SDG 12: Responsible Consumption and Production by promoting efficient and environmentally friendly consumption and production patterns. The biomass cycle formed within this system creates zero-waste agriculture, in which every production component has value and function. The integrated crop–livestock farming system optimizes the use of local resources and reduces dependence on chemical fertilizers and feed, thereby decreasing pressure on ecosystems and agricultural carbon emissions. The implementation of this concept establishes a sustainable agricultural model that not only maintains productivity but also strengthens the ecological and economic resilience of farming communities (Werner et al., 2024).

3.4 The impact of ICLS implementation on sustainable food security

The improvement of food security performance across Indonesia can be observed in Table 6**.** The data indicate that the average food security index/*indeks ketahanan pangan (IKP)* has shown a gradual upward trend between 2022 and 2024, particularly in provinces that have implemented Integrated Crop–Livestock Systems (ICLS) more extensively. This improvement reflects the contribution of ICLS in strengthening local food systems through enhanced soil fertility, diversified agricultural outputs, and the sustainable use of biomass resources.

Table 6. Average food security index/*indeks ketahanan pangan (IKP)* per province in Indonesia

Year	Province	Average food security index	Food Security Category
2022	Aceh	69.96	Very Resistant
	Bali	85.2	Very Resistant
	Banten	73.78	Very Resistant
	Bengkulu	67.99	Resistent
	Special Region of Yogyakarta	80.88	Very Resistant
	Jakarta Special Capital Region	78.25	Very Resistant
	Gorontalo	80.35	Very Resistant
	Jambi	69.5	Resistent
	West Java	77.55	Very Resistant
	Central Java	82.95	Very Resistant
	East Java	79.85	Very Resistant
	West Kalimantan	70.81	Resistent
	South Kalimantan	81.05	Very Resistant
	Central Kalimantan	69.96	Very Resistant
	East Kalimantan	77.65	Very Resistant
	North Kalimantan	71.04	Very Resistant
	Bangka Belitung Islands	71.71	Very Resistant
	Riau Islands	63.83	Somewhat Vulnerable
	Lampung	78.61	Very Resistant
	Maluku	60.2	Somewhat Vulnerable
	North Maluku	58.39	Somewhat Vulnerable
	West Nusa Tenggara	76.58	Very Resistant
	East Nusa Tenggara	68.42	Resistant
	Papua	37.8	Very Vulnerable
	West Papua	45.92	Very Vulnerable
	Riau	67.59	Resistant
	West Sulawesi	74.04	Resistant
	South Sulawesi	81.38	Very Resistant
	Central Sulawesi	75.92	Very Resistant
	Southeast Sulawesi	75.04	Very Resistant
	North Sulawesi	74.3	Very Resistant
	West Sumatra	79.45	Very Resistant
	South Sumatra	69.64	Very Resistant
	North Sumatra	71.22	Resistant

2023	Aceh	72.96	Very Resistant
	Bali	87.65	Very Resistant
	Banten	78.72	Very Resistant
	Bengkulu	72.27	Resistant
	Special Region of Yogyakarta	83.17	Very Resistant
	Jakarta Special Capital Region	83.8	Very Resistant
	Gorontalo	81.64	Very Resistant
	Jambi	72.17	Somewhat Resistant
	West Java	82.19	Very Resistant
	Central Java	84.8	Very Resistant
	East Java	82.46	Very Resistant
	West Kalimantan	72.2	Resistant
	South Kalimantan	81.26	Very Resistant
	Central Kalimantan	68.9	Very Resistant
	East Kalimantan	79.29	Very Resistant
	North Kalimantan	74.59	Very Resistant
	Bangka Belitung Islands	71.14	Somewhat Resistant
	Riau Islands	65.1	Somewhat Vulnerable
	Lampung	81.55	Very Resistant
	Maluku	64.37	Somewhat Vulnerable
	North Maluku	62.34	Somewhat Vulnerable
	West Nusa Tenggara	76.51	Very Resistant
	East Nusa Tenggara	71.25	Resistant
	Papua	42.27	Very Vulnerable
	West Papua	47.95	Vulnerable
	Riau	68.68	Resistant
	West Sulawesi	73.03	Somewhat resistant
	South Sulawesi	83.36	Very Resistant
	Central Sulawesi	75.83	Very Resistant
	Southeast Sulawesi	74.96	Very Resistant
	North Sulawesi	77.32	Very Resistant
	West Sumatra	83.22	Very Resistant
	South Sumatra	73.82	Very Resistant
	North Sumatra	75.97	Very Resistant
2024	Aceh	73.94	Very Resistant
	Bali	88.23	Very Resistant
	Banten	79.26	Very Resistant
	Bengkulu	73.39	Resistant
	Special Region of Yogyakarta	84.15	Very Resistant
	Jakarta Special Capital Region	85.13	Very Resistant
	Gorontalo	81.47	Very Resistant
	Jambi	74.94	Resistant
	West Java	82.97	Very Resistant
	Central Java	85.34	Very Resistant
	East Java	83.86	Very Resistant
	West Kalimantan	73.49	Very Resistant
	South Kalimantan	82.95	Very Resistant
	Central Kalimantan	70.16	Very Resistant
	East Kalimantan	78.61	Very Resistant
	North Kalimantan	75.77	Very Resistant
	Bangka Belitung Islands	70.21	Somewhat resistant
	Riau Islands	66.29	Somewhat resistant
	Lampung	82.58	Very Resistant
	Maluku	62.68	Somewhat resistant
	North Maluku	61.44	Somewhat Vulnerable
	West Nusa Tenggara	78.44	Very Resistant
	East Nusa Tenggara	70.91	Resistant
	Papua	40.21	Very Vulnerable
	West Papua	51.36	Vulnerable
	Riau	70.42	Resistant

West Sulawesi	71.99	Very Resistant
South Sulawesi	83.82	Very Resistant
Central Sulawesi	76.87	Very Resistant
Southeast Sulawesi	76.68	Very Resistant
North Sulawesi	76.32	Very Resistant
West Sumatra	84.32	Very Resistant
South Sumatra	74.07	Very Resistant
North Sumatra	77.49	Very Resistant

(Badan Pangan Nasional, 2024)

The data in Table 6 show that the national food security index/*indeks ketahanan pangan (IKP)* average value increased gradually during the 2022–2024 period, from around 71.4 to 74.8, with most provinces showing a positive upward trend. This increase indicates a structural strengthening of the food system across various regions, in line with the broader implementation of the Integrated Crop–Livestock Systems (ICLS). Several provinces with high levels of ICLS adoption, such as Central Java, West Nusa Tenggara, and South Sulawesi, recorded an average food security index above 75, indicating relatively "resilient" and sustainable food conditions. The integration of crops and livestock reduces dependence on external inputs and promotes agroecological intensification, meaning productivity improvements without causing environmental degradation. Thus, the improvement in food security performance at the provincial level demonstrates that the implementation of ICLS contributes significantly to the development of a more balanced, efficient, and environmentally resilient agricultural system (Sekaran et al., 2021).

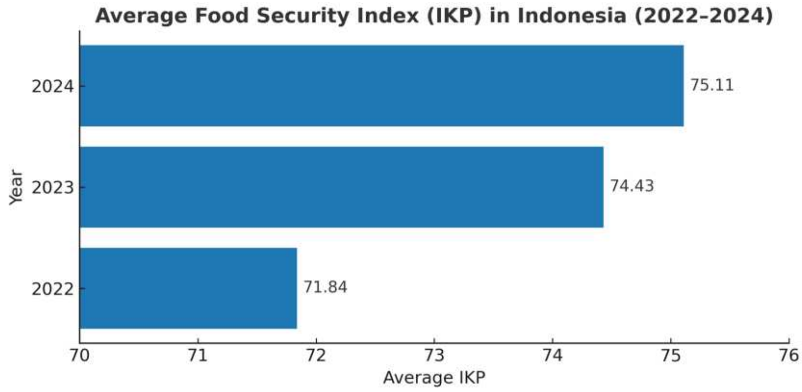


Fig. 6. Average food security index/*indeks ketahanan pangan (IKP)* in Indonesian (2022-2024)

From a spatial perspective, provinces in eastern Indonesia such as Papua and Maluku show slower food security index growth compared to those in the western and central regions. The IKP values in these two provinces remained in the range of 65–68 in 2024, which is categorized as "somewhat vulnerable." This condition can be attributed to limited agricultural infrastructure, market access, and local technological capacity. However, the implementation of locally based ICLS, such as the integration of root crops with cattle and pig farming, has begun to show positive results in strengthening food availability and income stability. The adoption of integrative models in marginal areas has proven to improve food resilience through input efficiency and biomass circulation (Sekaran et al., 2021) In aggregate, provinces with food security index/*indeks ketahanan pangan (IKP)* values above 75 tend to have higher agricultural subsector diversification and stronger institutional support for ICLS practices. Conversely, regions with IKP values below 70 are generally still dominated by monoculture systems and have limited access to organic fertilizer technology and fermented feed. This correlation indicates that the intensity of ICLS implementation has a positive relationship with improvements in regional food security. The synergy between crops and livestock creates closed nutrient loops that maintain long-term productivity and reduce vulnerability to environmental degradation (Sekaran et al., 2021).

The increase in the national food security index average, as shown in the gh, indicates significant progress in the aspects of food availability, accessibility, and stability in Indonesia during the 2022–2024 period. This positive trend not only reflects the enhancement of agricultural production capacity but also marks a transformation toward a more sustainable production system through the implementation of Integrated Crop–Livestock Systems across various regions (Colazo et al., 2022). The transformation of agricultural systems toward more efficient and regenerative models, such as ICLS, has contributed to improving productivity while maintaining the sustainability of natural resources. The implementation of ICLS directly contributes to national food security by integrating crop and livestock subsectors within a single, efficient production cycle. Agricultural residues are utilized as livestock feed, while livestock manure is processed into organic fertilizer, creating a localized resource circulation that minimizes waste and enhances soil productivity. This mechanism strengthens the stability of nutritious food supply. By reusing crop residues as animal feed and processing livestock waste into organic fertilizers, ICLS creates biomass cycles that reduce dependence on external inputs and maximize the use of local resources. In addition to strengthening food security, the implementation of ICLS is also aligned with SDG 13 (Climate Action) and SDG 15 (Life on Land). From a climate perspective, this system reduces reliance on synthetic fertilizers, whose production contributes to greenhouse gas emissions. The use of organic fertilizers derived from livestock waste and the reduction of straw burning help lower carbon emissions and increase soil carbon sequestration**,** thereby supporting climate change mitigation efforts. From the perspective of terrestrial ecosystem sustainability, ICLS helps maintain soil structure and fertility through crop rotation and grazing land integration, which reduces the risks of degradation and erosion. The integration between crops and livestock within the ICLS framework enhances soil organic carbon content and improves the ecological functions of agricultural land. This improvement in soil quality, in turn, contributes to increased agricultural productivity and long-term food security (Colazo et al., 2022).

4. Conclusions

The Integrated Crop–Livestock System (ICLS) 5.0 provides a holistic innovation that unites agricultural and livestock components into a sustainable circular model. This system forms a continuous nutrient cycle where agricultural residues are processed into fermented forage, and livestock manure is transformed into organic fertilizer. The interaction between both elements creates a closed-loop ecosystem that minimizes waste, improves soil fertility, and enhances feed efficiency. As a result, agricultural production becomes more stable and environmentally sustainable, while the dependence on external inputs such as chemical fertilizers and industrial feed is significantly reduced.

Over the past three years (2022–2024), the implementation of ICLS 5.0 in several regions of Indonesia has shown tangible impacts on nutritional and food security performance. National data indicate that average energy intake increased from 2,079.09 kcal to 2,095.54 kcal per capita, while protein intake rose from 62.21 grams to 63.70 grams per capita. At the same time, the national Food Security Index consistently improved, with more provinces shifting into the “resistant” and “very resistant” categories. These findings demonstrate that the integration of crops and livestock contributes directly to improving food availability, nutritional quality, and community resilience, particularly in rural areas that previously faced limited access to affordable and nutritious food.

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Author Contribution

Conceptualization, K.D.F.; Software, K.D.F.; Validation, K.D.F.; Investigation, K.D.F.; Resources, M.E.R.; Methodology, K.DF and M.F.Y.R.M.P.; Data Curation, K.D.F.; Writing–Original Draft Preparation, K.D.F., M.E.R., and M.F.Y.R.M.P.; Writing – Review & Editing, K.D.F., and M.F.Y.R.M.P.; Visualization, K.D.F., and M.E.R.; Supervision, K.D.F.; Project Administration, K.D.F.

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Ethical Review Board Statement

Ethical review and approval were waived for this study due to the use of previously published secondary data obtained from existing literature, which did not involve direct interaction with human or animal subjects and did not collect any new personal or sensitive information.

Informed Consent Statement

Informed consent was not required for this study because the human-related data were obtained from secondary sources and were fully anonymized, containing no identifiable personal information.

Data Availability Statement

The data supporting the findings of this study are available in previously published research sources referenced within this manuscript. Additional information or clarification regarding the utilized datasets can be provided by the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflict of interest. As the study received no external funding, no external party influenced the study design, data collection, analysis, manuscript preparation, or the decision to publish.

Declaration of Generative AI Use

The authors declare that no generative artificial intelligence tools were used in the preparation, writing, analysis, or editing of this manuscript. All contents were produced entirely through the authors’ own reasoning, interpretation, and analysis based on existing data and published literature.

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