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Integrative Model of Farmer Empowerment and Optimization of Beef Cattle Management on Suboptimal Land in Minahasa Regency

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ABSTRACT

This study aims to analyze the technical, socio-economic, and institutional conditions of farmers in implementing an Integrated Farming System (IFS) on suboptimal land in Minahasa Regency and evaluate the effects of crop–beef cattle integration on farm productivity, farming efficiency, and farmers' welfare. The study employed a survey of 180 farming households across nine districts in Minahasa Regency. Data were analyzed using descriptive analysis, simple and multiple linear regression, and DEA. The results indicate that technical conditions ($\beta = 0.412$; $p < 0.001$), socio-economic conditions ($\beta = 0.287$; $p < 0.001$), and institutional conditions ($\beta = 0.356$; $p < 0.001$) positively influence IFS implementation, with the model explaining 59.3% of the variation ($R^2 = 0.593$). Crop–beef cattle integration significantly improves farm productivity ($\beta = 0.618$; $p < 0.001$; $R^2 = 0.582$) and farming efficiency ($\beta = 0.541$; $p < 0.001$; $R^2 = 0.511$). DEA results indicate that 33.9% of farmers were technically efficient, 45.6% moderately efficient, and 20.6% inefficient. Furthermore, farm productivity ($\beta = 0.441$; $p < 0.001$) and farming efficiency ($\beta = 0.376$; $p < 0.001$) significantly improve farmers' welfare, with the model explaining 64.7% of the variation ($R^2 = 0.647$). These findings highlight the importance of strengthening farmers' technical capacity, institutional support, agricultural extension, access to financing, and crop–livestock integration to improve productivity, efficiency, and sustainable beef cattle agribusiness on suboptimal land.

Keywords: Efficiency; Welfare; Suboptimal Land; Empowerment; Productivity; Integrated Farming

INTRODUCTION

Agricultural and livestock development in Indonesia is directed toward increasing production, productivity, efficiency, and competitiveness to support food security and improve farmers' welfare. The agricultural sector plays a strategic role not only as a provider of food but also as a source of income for rural communities and a driver of regional development. Nevertheless, Lainawa et al. (2024) reported that agricultural households continue to face various structural constraints, particularly limited land ownership, which contributes to low productivity and farmers' income. These challenges become more severe in suboptimal areas, especially acidic drylands characterized by low soil fertility, limited organic matter content, and inadequate water availability.

Minahasa Regency possesses considerable agricultural land resources with significant potential for both intensive and extensive beef cattle development. However, this potential has not been fully utilized, particularly in suboptimal lands that still face limitations in management technology and the efficient use of local resources (Kalangi et al., 2022; Lainawa et al., 2025; Lainawa et al., 2026; Lenzun et al., 2023). Beef cattle production systems remain predominantly traditional, small-scale, and poorly integrated with food crop and plantation farming systems (Lainawa et al., 2025). Consequently, farming efficiency remains low, agricultural residues are underutilized as livestock feed, and livestock waste has not been optimally used as organic fertilizer to improve land productivity.

In recent years, the Integrated Farming System (IFS) and Integrated Crop and Livestock System (ICLS) approaches have emerged as important strategies for sustainable agricultural development. These systems emphasize the integration of crop and livestock enterprises through the synergistic utilization of resources to enhance production efficiency, land productivity, and environmental sustainability. Qamara et al. (2025) argued that crop–livestock integration improves the utilization of local resources and strengthens the sustainability of agricultural systems. Similarly, Shanmugam et al. (2024) demonstrated that IFSs contribute to increased farm productivity, higher farmers' income, and improved environmental sustainability. Furthermore, Karthik et al. (2024) confirmed that IFS models for smallholder farmers significantly enhance both productivity and farm profitability.

In the Indonesian context, IFS and ICLS approaches have also been shown to strengthen agribusiness integration and farmer empowerment (Nurwenda & Saepudin, 2024). The utilization of crop residues as livestock feed and livestock manure as organic fertilizer creates a more efficient production cycle while reducing dependence on external inputs. Nevertheless, previous studies have generally focused on technical cultivation practices, production efficiency, or the ecological benefits of crop–livestock integration in isolation. Comprehensive studies simultaneously integrating technical, socio-economic, and institutional dimensions within a single analytical framework remain limited, particularly in the context of IFSs on suboptimal lands. Alderkamp (2025) emphasized that sustainable integrated farming development requires a multidimensional approach encompassing technical, social, economic, and institutional aspects.

This research gap indicates that relatively few studies have developed conceptual or empirical models capable of explaining the interrelationships among farmers' technical conditions, socio-economic characteristics, institutional support, crop–livestock integration, improvements in farm productivity and efficiency, and their subsequent effects on farmers' welfare within a unified framework. Most previous studies have examined only partial relationships among these variables and therefore have not comprehensively explained the mechanisms underlying IFS development. Moreover, research on IFSs in the suboptimal lands of Minahasa Regency that incorporates farmer empowerment as a central component of the development model remains scarce.

In this context, farmer empowerment is a crucial factor supporting the successful implementation of IFSs. Empowerment extends beyond improving technical capacity and includes strengthening farmers' access to technology, financial capital, information, and institutional support. Lainawa et al. (2024) explained that suboptimal lands in Minahasa Regency possess substantial development potential through technological innovation and multi-stakeholder collaboration. Furthermore, Milliet et al. (2024) emphasized that strengthening collaborative networks and institutional arrangements can enhance farmers' adaptive capacity in addressing the challenges of modern agricultural development.

Based on these conditions, this study addresses the identified research gap by developing an integrative model that combines technical, socio-economic, and institutional dimensions within a farmer-empowerment-based IFS. Specifically, the study aims to: (1) analyze the technical, socio-economic, and institutional conditions of farmers; (2) examine the effects of crop–beef cattle integration on farm productivity and farming efficiency; (3) analyze the effects of productivity and efficiency on farmers' welfare; and (4) develop an adaptive and sustainable IFS model based on farmer empowerment and optimized beef cattle management.

The novelty of this study lies in the development of an integrative model that links farmers' technical, socio-economic, and institutional conditions with IFS implementation and further explains their effects on farm productivity, farming efficiency, farmers' welfare, farmer empowerment, and beef cattle management optimization within a single conceptual framework. Unlike previous studies that examined these factors separately, this study adopts a multidimensional approach tailored to the characteristics of suboptimal land in Minahasa Regency. The findings are expected to contribute to the advancement of theory and provide practical guidance for sustainable agricultural and livestock development in regions with similar conditions.

LITERATURE REVIEW

Theoretical and Empirical Review of IFS Development on Suboptimal Land

Several studies have shown that Minahasa Regency has significant potential for the development of beef cattle agribusiness based on IFSs, although its utilization remains suboptimal. Lainawa et al. (2024) identified that the availability of agricultural land supports both extensive and intensive beef cattle production systems; however, their implementation is still constrained by limited management technology and weak integration among farming subsectors. Most farmers raise cattle on small landholdings of less than 0.5 hectares, while extensive marginal lands remain underutilized for productive agricultural activities. Furthermore, Lainawa et al. (2025) found that the integration of beef cattle with food crop farming is economically and socially feasible, yet its ecological contribution, particularly the utilization of livestock waste as organic fertilizer, has not been optimized to sufficiently meet crop nutrient requirements.

Theoretically, the development of IFSs on suboptimal land is grounded in Sustainable Agriculture Theory, which emphasizes the balance between economic, social, and environmental aspects through the optimization of local resources, input efficiency, business diversification, and waste reduction. In this context, the integration of crops and livestock creates a synergistic relationship through the utilization of crop residues as animal feed and livestock waste as organic fertilizer, thereby improving both the ecological and economic efficiency of farming systems.

According to Shepovalova et al. (2023), the optimization of suboptimal land requires an integrated agroecosystem approach through the application of organic fertilizers, soil conservation practices, and the strengthening of farmers' capacities. The success of this system is also influenced by farmer empowerment, institutional strengthening, access to technology, and the technical efficiency of farming enterprises, which can be measured using the Data Envelopment Analysis (DEA) approach (Asnamawati et al., 2024; Lenzun et al., 2023; Xue et al., 2024).

Hypotheses Development

Technical, Socio-Economic, and Institutional Conditions of Farmers on the Implementation of IFSs

The development of IFSs on suboptimal land requires adequate technical, socio-economic, and institutional support among farmers. Sustainable Agriculture Theory explains that the success of IFSs is influenced by farmers' ability to manage land resources, technology, capital, and institutional aspects efficiently and sustainably. In this context, the technical aspect includes mastery of cultivation technology, management of agricultural and livestock waste, feed provision, and the ability to adapt to the characteristics of suboptimal land. The better the farmers' technical capacity, the greater the opportunity for successful crop–livestock integration.

From the socio-economic perspective, factors such as education level, farming experience, access to capital, asset ownership, and income influence farmers' ability to adopt integrated farming innovations. Purnomo et al. (2023) found that the integration of rice farming and beef cattle production in Indonesia still faces several constraints, including limited farmer capacity, restricted access to technology, and inadequate economic support. In addition, institutional factors such as farmer groups, agricultural extension services, government support, business partnerships, and market access also play an important role in improving farming efficiency. Lainawa et al. (2024) emphasized that farmer empowerment and institutional strengthening can enhance the capacity of beef cattle farming enterprises in North Sulawesi.

H1: Farmers' technical conditions have a positive effect on the implementation of IFSs.
H2: Farmers' socio-economic conditions have a positive effect on the implementation of IFSs.
H3: Farmers' institutional conditions have a positive effect on the implementation of IFSs.

The Integration of Crops and Beef Cattle on Farm Productivity and Farming Efficiency

The concept of the IFS emphasizes the synergistic relationship between crop and livestock subsystems through the circular and sustainable utilization of resources. In this system, crop residues are utilized as livestock feed, while livestock waste is used as organic fertilizer to improve soil fertility. This approach can enhance the efficiency of production input utilization while reducing dependence on external inputs.

A recent study by Lainawa et al. (2026) in Minahasa Regency also demonstrated that the integration of beef cattle, rice, and maize farming on suboptimal land has high potential for technical efficiency and economic competitiveness when supported by technological innovation, the utilization of agricultural waste, and the strengthening of farmer institutions. The use of rice straw and corn residues as silage was also found to improve year-round feed availability, thereby optimizing beef cattle productivity. This integration not only increases farm productivity but also creates production cost efficiency through reduced expenditures on chemical fertilizers and commercial feed. Therefore, the integration of crops and beef cattle is expected to have a positive effect on farm productivity and farming efficiency on suboptimal land. Based on the above explanation, the research hypotheses are formulated as follows:

H4: The integration of crops and beef cattle has a positive effect on farm productivity on suboptimal land in Minahasa Regency.
H5: The integration of crops and beef cattle has a positive effect on farming efficiency on suboptimal land in Minahasa Regency.

Farm Productivity and Farming Efficiency on Farmer Welfare
In the theory of sustainable agricultural development, increasing farm productivity and farming efficiency are important indicators for improving farmer welfare. Productivity reflects farmers' ability to generate higher output from available resources, while farming efficiency refers to the ability to minimize production costs in order to obtain optimal profits. IFSs enable the diversification of income sources through crop–livestock integration, thereby reducing farming risks and improving the economic stability of farmer households.

A study by Villano et al. (2025) on farmer empowerment in integrated livestock systems in Indonesia demonstrated that improving farmers' capacity and increasing household involvement in livestock enterprises contribute positively to the economic and social welfare of rural communities. Therefore, increasing farm productivity and farming efficiency through the integration of crops and beef cattle is expected to have a positive effect on farmer welfare in Minahasa Regency. Based on the above discussion, the following hypotheses are proposed:

H6: Farm productivity has a positive effect on farmer welfare in IFSs based on suboptimal land in Minahasa Regency.
H7: Farming efficiency has a positive effect on farmer welfare in IFSs based on suboptimal land in Minahasa Regency.

Farmer Empowerment and Optimization of Beef Cattle Management toward the Development of an Integrative Model
Farmer empowerment is a process of enhancing the capacity of individuals and groups to independently access resources, technology, information, capital, and decision-making opportunities. Within the framework of Community Empowerment Theory, empowerment is viewed as an important strategy for improving the economic independence of rural communities through the strengthening of social capacity, institutional systems, and local economic development. The success of IFSs is determined not only by technical production factors but also by farmers' ability to adopt innovations, establish business networks, and collectively manage resources.

A study by Ramdani (2023) demonstrated that farmer empowerment models based on livestock integration can improve business sustainability, farmer participation, and the effectiveness of beef cattle agribusiness management. Community empowerment through livestock enterprises also contributes to increased income, food security, and social cohesion in rural communities. Based on the theoretical and empirical review, the following hypotheses are proposed:

H8: Farmer empowerment has a positive effect on the development of an integrative model of IFSs based on suboptimal land in Minahasa Regency.

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H9: Optimization of beef cattle management has a positive effect on the development of an integrative model of IFSs based on suboptimal land in Minahasa Regency.

Conceptual Framework

Figure 1. Research Framework

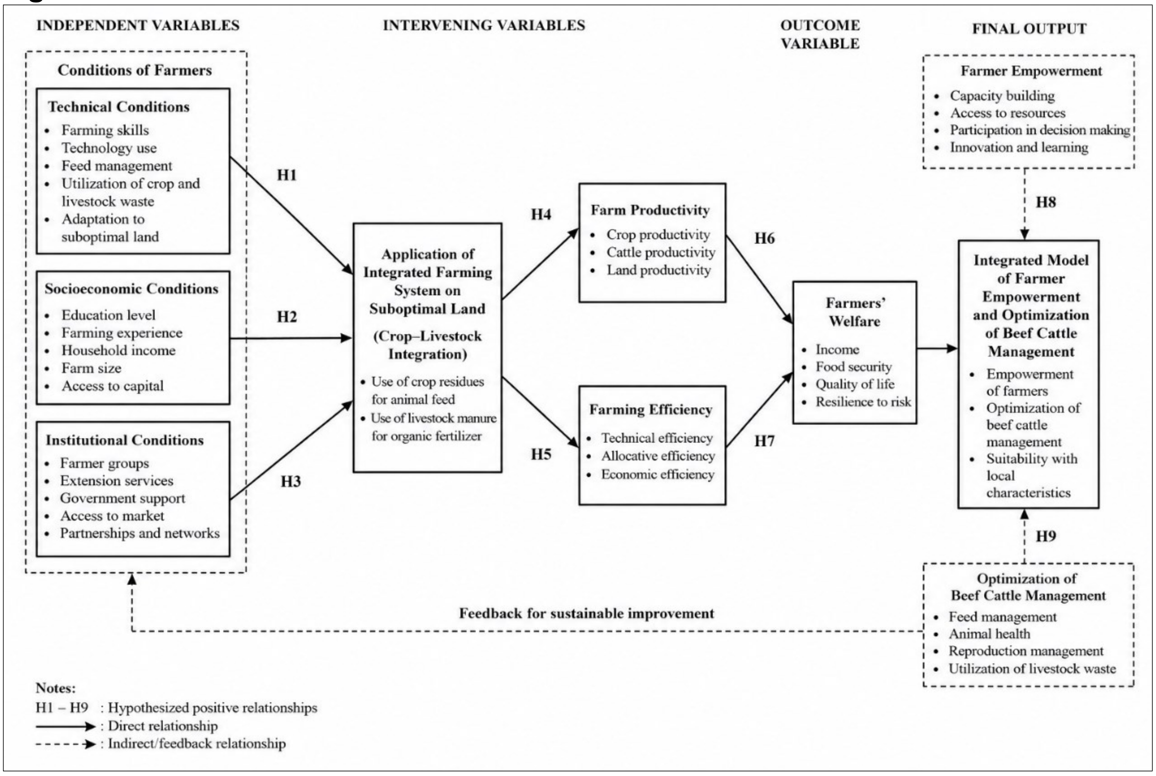

Figure 1 illustrates the conceptual relationships among variables in this study concerning the development of IFSs based on suboptimal land in Minahasa. The framework explains that the successful implementation of an IFS, particularly crop-livestock integration on suboptimal land, is influenced by several independent variables, namely farmers' technical conditions, socio-economic conditions, and institutional conditions.

RESEARCH METHOD

Research Approach

This study employed a quantitative approach supported by descriptive and explanatory analyses to examine the development of an IFS based on crop–livestock integration on suboptimal land in Minahasa Regency. The quantitative approach was used to measure the relationships among research variables, including technical conditions, socio-economic conditions, institutional conditions, crop–livestock integration, farm productivity, farming efficiency, farmers' welfare, farmer empowerment, and the optimization of beef cattle management. In addition, the descriptive approach was applied to describe farmer characteristics and the condition of IFSs in the research area.

Research Design

This study employed a survey design using a cross-sectional approach, in which data were collected at a specific point in time from farmer households implementing integrated crop–livestock farming systems on suboptimal land in Minahasa Regency. The research locations covered nine districts, namely Tombulu, Tompaso, West Tompaso, Sonder, Kawangkoan, West Kawangkoan, East Langowan, West Langowan, and South Langowan. These areas were selected purposively because they have considerable potential for the development of IFSs based on crop and beef cattle integration, although they still face various technical, socio-economic, and institutional constraints. The unit of analysis in this study was farmer households integrating food crops, plantation crops, or horticultural farming with beef cattle production on suboptimal land.

Sampling Method

The study population consisted of all beef cattle farmer households that had implemented or had the potential to implement IFSs on suboptimal land in Minahasa Regency. The sampling technique employed a combination of multistage purposive sampling and stratified random sampling.

The first stage was conducted purposively to determine the research districts based on the characteristics of suboptimal land and the existence of smallholder beef cattle farming activities. The second stage involved stratification based on farming type and land ownership size. Subsequently, respondents were selected proportionally and randomly within each stratum.

A total of 180 farmer households were selected as respondents in this study. The stratified random sampling method was considered appropriate because it was able to represent the heterogeneity of farmer characteristics based on farm scale, land conditions, and the level of farming system integration. A study by Lainawa et al. (2025) on the cattle–rice–maize integration system in Minahasa Regency also applied a stratification approach to distinguish traditional, semi-commercial, and commercial farming systems. Recent studies have shown that factors such as age, farming experience, extension services, and access to capital significantly influence the implementation of crop–livestock integration systems (Purnomo et al., 2023).

Data Collection Method

This study utilized both primary and secondary data sources. Primary data were collected through field observations, in-depth interviews, Focus Group Discussions (FGDs), structured interviews, and questionnaires administered to farmer households engaged in crop–livestock farming systems. The data collection process aimed to identify technical, socio-economic, and institutional conditions, farming constraints, as well as development strategies for IFSs based on crop and beef cattle integration.

Secondary data were obtained from the Central Bureau of Statistics (BPS), the Department of Agriculture and Livestock Services of Minahasa Regency, research reports, scientific literature, and government policy documents. The research instrument employed a 1–5 Likert scale to measure farmers' perceptions and the level of implementation of IFSs, with the following score categories: 1 = very low, 2 = low, 3 = moderate, 4 = good, and 5 = very good. Survey methods and structured interviews were considered effective in describing technical and socio-economic conditions as well as farmers' perceptions regarding crop–livestock integration (Roessali et al., 2022).

Data Analysis Method

Data analysis was conducted using descriptive and inferential statistical approaches to examine the relationships among variables in developing an IFS based on crop–beef cattle integration on suboptimal land in Minahasa Regency. Descriptive statistics were used to summarize respondents' characteristics, including age, education, farming experience, landholding size, and beef cattle ownership, while inferential analysis was employed to test the proposed hypotheses and develop the integrated farming model.

All variables were measured using a structured questionnaire with a five-point Likert scale. Technical conditions were assessed through feed management, utilization of crop and livestock residues, application of organic fertilizers, technology adoption, and adaptation to suboptimal land. Socio-economic conditions included household income, farming experience, family size, access to agricultural credit, and market access, whereas institutional conditions comprised participation in farmer groups, access to extension services, government support, business partnerships, and market information (Lainawa et al., 2024; Milliet et al., 2024).

IFS implementation was measured by the degree of integration between crop and beef cattle farming, including the utilization of crop residues as livestock feed, the use of livestock manure as organic fertilizer, the efficient use of local resources, and the implementation of integrated production cycles (Qamara et al., 2025; Shanmugam et al., 2024). Farm productivity was evaluated through crop, livestock, and land productivity, while farm efficiency was estimated using DEA based on production inputs (land, labor, feed costs, and production costs) and outputs (crop production, livestock production, and farm income).

Farmer welfare was measured using household income, food security, quality of life, and the ability to cope with farming risks. In addition, farmer empowerment was assessed through decision-making capacity, access to productive resources, participation in farmer organizations, access to information and technology, and innovation capability. Beef cattle management optimization was evaluated through feed management, utilization of local feed resources, waste management, husbandry practices, animal health and reproduction, and integration with crop production. These constructs were integrated to develop a sustainable IFS model based on farmer empowerment and optimized beef cattle management, consistent with previous studies (Purnomo et al., 2023; Roessali et al., 2022).

Hypotheses H1–H3 were tested using multiple linear regression to examine the effects of technical, socio-economic, and institutional conditions on IFS implementation. H4 was analyzed using simple linear regression to evaluate the effect of IFS implementation on farm productivity. For H5, DEA was first applied to estimate technical efficiency scores, which were subsequently used as the dependent variable in a simple linear regression assessing the effect of IFS implementation on farm efficiency. H6 and H7 were examined using multiple linear regression to evaluate the effects of farm productivity and farm efficiency on farmer welfare, while H8 and H9 were tested using multiple linear regression to analyze the effects of farmer empowerment and beef cattle management optimization on the development of the sustainable IFS model. All analyses were conducted at a 5% significance level ($\alpha = 0.05$), with hypotheses accepted when the regression coefficient (β) was positive and the p-value was less than 0.05.

RESULTS

Respondents Characteristics

Table 1. Characteristics of Respondents

Variable	Category	Frequency (n)	Percentage (%)
Age	25–40 years	42	23.3
	41–55 years	96	53.3
	>55 years	42	23.3
Education	Elementary School	48	26.7
	Junior High School	54	30.0
	Senior High School	63	35.0
	University	15	8.3
Farming Experience	<10 years	39	21.7
	10–20 years	88	48.9
	>20 years	53	29.4
Land Ownership	<0.5 ha	71	39.4
	0.5–1.0 ha	69	38.3
	>1.0 ha	40	22.2
Number of Cattle	1–3 heads	103	57.2
	4–6 heads	56	31.1
	>6 heads	21	11.7

In Table 1, this study involved 180 farmer households implementing integrated crop–livestock farming systems. Respondents were selected based on their involvement in beef cattle farming and crop cultivation on suboptimal acidic dryland areas. The results showed that the majority of respondents were in the productive age category of 41–55 years (53.3%), indicating that integrated farming activities were predominantly carried out by economically active farmers. Most farmers had a secondary level of education and more than 10 years of farming experience, reflecting adequate practical knowledge in agricultural and livestock activities. However, the majority of respondents owned relatively small landholdings (<1 ha), which reflects the common characteristics of small-scale farming systems in Minahasa Regency.

Technical, Socioeconomic, and Institutional Conditions of Farmers

Technical Conditions

Table 2. Technical Condition Scores of Farmers

Indicator	Mean Score	Category
Feed Management	3.82	Moderate
Utilization of Crop Residues	4.11	Good
Organic Fertilizer Application	3.74	Moderate
Technology Adoption	3.45	Moderate
Adaptation to Suboptimal Land	3.68	Moderate

In Table 2, the results showed that crop residue utilization obtained the highest score (4.11), indicating that most farmers have used rice straw and corn residues as feed for cattle. However, the level of technology adoption remains relatively low due to limited access to machinery, training, and extension services. Farmers still rely on traditional livestock management practices and have limited knowledge of feed fermentation technology and manure processing techniques.

Socioeconomic Conditions

Table 3. Socioeconomic Characteristics of Farmers

Variable	Mean
Household Income (IDR/year)	52,584,000
Farming Experience (years)	16.40
Household Size (persons)	4.80

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Access to Credit Score	3.21
Market Access Score	3.56

In Table 3, the average annual household income of respondents was IDR 52,584,000, indicating that integrated farming activities are still small-scale and semi-commercial in nature. Limited access to agricultural credit and fluctuations in cattle prices are major constraints for farmers in increasing their production capacity. Nevertheless, farmers with better market access tend to show higher levels of participation in crop–livestock integration systems.

Institutional Conditions

Table 4. Institutional Conditions of Farmers

Indicator	Mean Score	Category
Participation in Farmer Groups	4.02	Good
Access to Extension Services	3.48	Moderate
Government Support	3.35	Moderate
Partnership Networks	3.12	Moderate
Access to Market Information	3.51	Moderate

In Table 4, the institutional analysis showed that farmer group participation was relatively strong, while partnership networks and government support remained limited. Extension services have not been evenly distributed across all study areas, particularly in remote villages with inadequate transportation access. These conditions affect farmers' ability to efficiently adopt innovations in IFSs.

Effect of Technical, Socioeconomic, and Institutional Conditions on Integrated Farming Implementation

Table 5. Multiple Regression Analysis of Factors Affecting IFS Implementation

Variable	Coefficient (β)	t-value	Sig.
Technical Conditions	0.412	5.276	0.000
Socioeconomic Conditions	0.287	3.814	0.000
Institutional Conditions	0.356	4.592	0.000
Constant	0.936	2.746	0.007
R^2	0.593		

In Table 5, the multiple regression analysis showed that technical conditions ($\beta = 0.412$; $t = 5.276$; $p < 0.001$), socioeconomic conditions ($\beta = 0.287$; $t = 3.814$; $p < 0.001$), and institutional conditions ($\beta = 0.356$; $t = 4.592$; $p < 0.001$) all had significant positive effects on IFS implementation. The model explained 59.3% of the variation in IFS implementation ($R^2 = 0.593$), indicating that farmers' technical capacity, socioeconomic resources, and institutional support jointly determine the successful adoption of crop–livestock integration.

The Role of Crop–Livestock Integration on Productivity and Farming Efficiency

Farm Productivity Analysis

Table 6. Regression Analysis of Crop–Livestock Integration on Productivity

Variable	Coefficient (β)	t-value	Sig.
Crop–Livestock Integration	0.618	9.842	0.000
Constant	1.472	3.921	0.001
R^2	0.582		

In Table 6, the regression analysis results showed that crop–livestock integration had a significant effect on farm productivity ($\beta = 0.618$; $p < 0.001$). The positive coefficient indicates that an increase in integration activities, such as the use of manure fertilizer and the utilization of crop residues as livestock feed, contributes positively to both crop and beef cattle productivity. The R^2 value of 0.582 indicates that 58.2% of the variation in productivity can be explained by the implemented integration model.

This finding indicates that IFSs are capable of improving nutrient cycling and reducing dependence on external inputs. Farmers who apply feed conservation practices and manure recycling achieve higher productivity levels compared to those still practicing conventional farming methods.

Farming Efficiency Analysis

Table 7. DEA Efficiency Scores of Integrated Farming

Efficiency Category	Number of Farmers	Percentage (%)
Efficient (≥0.90)	61	33.9
Moderately Efficient (0.70–0.89)	82	45.6
Inefficient (<0.70)	37	20.6

In Table 7, the DEA analysis results showed that only 33.9% of farmers achieved a high level of technical efficiency. Most respondents were categorized as moderately efficient due to limitations in feed quality, labor allocation, and production technology. Farmers who integrated cattle manure into their crop production systems demonstrated better efficiency performance because they were able to significantly reduce fertilizer costs.

Table 8. Regression Analysis of Crop–Livestock Integration on Farming Efficiency

Variable	Coefficient (β)	t-value	Sig.
Crop–Livestock Integration	0.541	7.362	0.000
Constant	1.286	3.482	0.001
R^2	0.511		

After obtaining the DEA efficiency scores, a simple linear regression analysis was conducted to examine the effect of crop–livestock integration on farming efficiency. As presented in Table 8, crop–livestock integration significantly improved farming efficiency ($\beta = 0.541$; $t = 7.362$; $p < 0.001$). The regression model explained 51.1% of the variation in DEA efficiency scores ($R^2 = 0.511$).

Effect of Productivity and Efficiency on Farmers' Welfare

Table 9. Multiple Regression Results on Farmers' Welfare

Variable	Coefficient (β)	t-value	Sig.
Farm Productivity	0.441	6.228	0.000
Farming Efficiency	0.376	5.492	0.000
Constant	1.118	2.817	0.005
R^2	0.647		

In Table 9, the results of the study showed that farm productivity and farming efficiency had a significant effect on farmer welfare. Farm productivity had the strongest influence ($\beta = 0.441$), followed by farming efficiency ($\beta = 0.376$). The research model was able to explain 64.7% of the variation in farmer welfare.

An increase in productivity can improve household income, food availability, and farmers' economic resilience. Similarly, improved farming efficiency can reduce operational costs and increase profit margins. Farmers who implemented crop–livestock integration systems experienced better living conditions compared to those who did not adopt IFSs.

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Development of an Integrated Farmer Empowerment and Beef Cattle Optimization Model

Table 10. Multiple Regression Analysis of Farmer Empowerment and Beef Cattle Management Optimization on Integrated Model Development

Variable	Coefficient (β)	t-value	Sig.
Farmer Empowerment	0.483	6.957	0.000
Beef Cattle Management Optimization	0.529	7.641	0.000
Constant	1.201	3.274	0.001
R^2	0.671		

As shown in Table 10, farmer empowerment (β = 0.483; t = 6.957; $p < 0.001$) and beef cattle management optimization (β = 0.529; t = 7.641; $p < 0.001$) significantly influenced the development of the integrated farming model. The model explained 67.1% of the variation in integrated model development ($R^2 = 0.671$), indicating that strengthening farmers' capacity and improving livestock management are fundamental components of sustainable IFSs.

Table 11. Priority Components of the Integrated Development Model

Component	Mean Score	Priority Rank
Farmer Capacity Building	4.58	1
Feed Resource Optimization	4.47	2
Institutional Strengthening	4.32	3
Access to Agricultural Credit	4.21	4
Livestock Waste Utilization	4.15	5
Market Integration	4.08	6

According to Table 11, the integrated development model emphasizes farmer empowerment, optimization of feed resources, and institutional strengthening as key priorities in the development of a sustainable IFS in Minahasa Regency. Capacity building through training and extension programs is considered important for improving technical knowledge and promoting innovation adoption among farmers.

The results of the study also show that optimizing locally available feed resources, including rice straw and corn residues, can significantly reduce feed shortages during the dry season. Strengthening farmer institutions as well as improving access to credit and markets are also important factors in supporting the development of sustainable agribusiness on suboptimal land.

Hypothesis Testing Summary

Table 12. Summary of Hypothesis Testing

Hypotheses		β Coefficient	t-value	p-value	Decision
H1	Technical conditions positively affect integrated farming implementation	0.412	5.276	<0.001	Accepted
H2	Socioeconomic conditions positively affect integrated farming implementation	0.287	3.814	<0.001	Accepted
H3	Institutional conditions positively affect integrated farming implementation	0.356	4.592	<0.001	Accepted
H4	Crop–livestock integration positively affects farm productivity	0.618	9.842	<0.001	Accepted

H5	Crop–livestock integration positively affects farming efficiency	0.541	7.362	<0.001	Accepted
H6	Farm productivity positively affects farmers' welfare	0.441	6.228	<0.001	Accepted
H7	Farming efficiency positively affects farmers' welfare	0.376	5.492	<0.001	Accepted
H8	Farmer empowerment positively affects integrated model development	0.483	6.957	<0.001	Accepted
H9	Beef cattle management optimization positively affects integrated model development	0.529	7.641	<0.001	Accepted

Based on Table 12, all hypothesized relationships are positive and statistically significant ($p < 0.001$); therefore, H1–H9 are accepted. Specifically, technical conditions ($\beta = 0.412$, $t = 5.276$), socioeconomic conditions ($\beta = 0.287$, $t = 3.814$), and institutional conditions ($\beta = 0.356$, $t = 4.592$) each have a positive and significant effect on the implementation of IFSs, supporting H1, H2, and H3, respectively. Furthermore, the integration of crops and beef cattle positively affects farm productivity ($\beta = 0.618$, $t = 9.842$) and farming efficiency ($\beta = 0.541$, $t = 7.362$), leading to the acceptance of H4 and H5. Farm productivity ($\beta = 0.441$, $t = 6.228$) and farming efficiency ($\beta = 0.376$, $t = 5.492$) also have positive and significant effects on farmers' welfare, supporting H6 and H7. In addition, farmer empowerment positively influences the development of an integrative IFS model ($\beta = 0.483$, $t = 6.957$), supporting H8, while optimization of beef cattle management also has a positive and significant effect on the development of the integrative IFS model ($\beta = 0.529$, $t = 7.641$), supporting H9. Overall, these findings indicate that all proposed hypotheses are supported by the empirical data.

DISCUSSION

Key Findings Analysis

H1: The Effect of Farmers' Technical Conditions on the Implementation of IFSs

The positive influence of farmers' technical conditions on IFS implementation indicates that technical capacity plays a fundamental role in facilitating the successful adoption of integrated crop–livestock farming systems on suboptimal land in Minahasa Regency. Technical conditions include feed management skills, utilization of agricultural and livestock waste, mastery of cultivation technology, and the ability to adapt to suboptimal land characteristics. The better the farmers' technical capacity, the higher the level of crop–beef cattle integration.

The utilization of crop residues as animal feed and livestock waste as organic fertilizer has been proven to improve input efficiency, enhance soil fertility, and increase farm productivity (Kaya et al., 2022; Ramadhani et al., 2022). In addition, the integration of agricultural and livestock waste can reduce dependence on inorganic inputs and strengthen the utilization of local resources (Istiqomah et al., 2022; Siregar et al., 2024). This is particularly important in the Minahasa Regency, where many farming areas are characterized by acidic and nutrient-deficient soils. Through the application of organic fertilizers derived from livestock manure, soil organic matter can be improved, nutrient availability can be increased, and soil water-holding capacity can be enhanced. Consequently, crop production becomes more stable despite the limitations of suboptimal land. However, the adoption level of modern technology remains low due to limited access to extension services, training, and production facilities. Therefore, improving farmers' technical capacity is an important factor in supporting the success of sustainable IFSs.

H2: The Effect of Socio-Economic Conditions on the Implementation of IFSs

The significant influence of farmers' socio-economic conditions suggests that education, farming experience, and access to productive resources are important factors supporting the adoption of integrated farming systems. Factors such as education level, farming experience, access to capital, and household income influence farmers' ability to adopt innovations and develop crop–beef cattle integration systems. Farmers with higher education levels and better experience tend to be more open to technology and are better able to manage farming risks effectively.

In addition, access to capital supports the improvement of production capacity, the development of livestock housing, and agricultural waste processing activities. These findings are consistent with the studies of Astuti et al. (2022) and Purnomo et al. (2023), which state that limited capital, low farmer capacity, and poor access to technology are the main constraints in implementing crop–livestock integration in Indonesia. This study also shows that income diversification through crop–livestock integration improves the economic stability of farmer households. However, limited access to formal financing and business investment remains a constraint in the development of IFSs in Minahasa Regency.

H3: The Effect of Institutional Conditions on the Implementation of IFSs

The results of the study showed that institutional conditions had a positive and significant effect on the implementation of IFSs. The presence of farmer groups, access to agricultural extension services, support from local government, and business partnerships play an important role in accelerating the adoption of integrated farming innovations. Farmers who are actively involved in farmer groups tend to have better levels of crop–livestock integration because these groups serve as a medium for technology transfer, improved market access, and business collaboration.

These findings are consistent with Tim et al. (2023), who emphasized that institutional strengthening and participatory extension services can enhance technology adoption, adaptive capacity, and the sustainability of IFSs on suboptimal land. In addition, strong institutions expand farmers' access to information, innovation, capital, and marketing networks, thereby supporting improvements in farm productivity and efficiency. Institutional support is particularly important in suboptimal land areas because farmers often face greater technical and financial challenges compared to those farming on more fertile land. Through collective action and institutional support, farmers can access resources and technologies that would otherwise be difficult to obtain individually. However, this study also found that limited numbers of extension workers, weak agribusiness partnerships, and inadequate infrastructure remain constraints in the development of IFSs in Minahasa Regency.

H4: The Effect of Crop–Beef Cattle Integration on Farm Productivity

The results of the study showed that the integration of crops and beef cattle had a positive effect on farm productivity. The utilization of crop residues as livestock feed and the application of organic fertilizer derived from livestock waste were able to improve soil fertility, enhance resource use efficiency, and sustainably increase crop productivity. Farmers who implemented integrated systems showed higher land and livestock productivity compared to those using non-integrated systems.

These findings are consistent with the study by Nayak et al. (2023), which states that crop–livestock integration has higher technical efficiency and productivity compared to conventional farming systems. Crop–beef cattle integration also improves year-round feed availability through the use of rice straw and corn residues as silage, particularly on suboptimal land. The increase in productivity occurs because the integrated system creates a mutually beneficial biological cycle between crops and livestock. Crop residues that previously had little economic value are converted into livestock feed, while livestock manure is recycled into organic fertilizer that improves soil fertility and nutrient cycling. This circular flow of resources enhances the productivity of both crop and livestock enterprises simultaneously. In addition to increasing productivity, the integrated system provides ecological benefits by improving soil structure, increasing microbial activity, and enhancing nutrient cycling, which are essential for maintaining agricultural production on suboptimal land. However, productivity among farmers still varies due to differences in technical skills, farm management, land size, and access to technology and agricultural extension services.

H5: The Effect of Crop–Beef Cattle Integration on Farm Efficiency
The results of the study showed that the integration of crops and beef cattle had a positive effect on farm efficiency. The integrated system enables farmers to reduce production costs through the utilization of crop residues as livestock feed and livestock waste as organic fertilizer. The DEA analysis results indicated that farmers who applied integrated systems achieved higher technical efficiency levels compared to non-integrated farmers.

The use of organic fertilizer helps reduce chemical fertilizer costs, while the utilization of agricultural residues reduces dependence on commercial feed. These findings support previous studies showing that agroecology-based IFSs improve energy efficiency, enhance soil fertility, and reduce environmental impacts through the use of organic waste and more efficient utilization of feed and nutrients (Oenema & Oenema, 2022; Palsaniya et al., 2022). In the context of Minahasa Regency, where production costs are often constrained by limited access to external inputs, IFSs increase efficiency by maximizing locally available resources. The recycling of nutrients and biomass within the farming system reduces waste, lowers input expenditures, and improves the overall economic performance of farm households.

However, efficiency levels are still influenced by farm scale, management quality, and farmers' access to technology.

H6, H7: The Effect of Productivity and Efficiency on Farmers' Welfare
The results of the study showed that farm productivity and efficiency had a positive effect on farmers' welfare. Increased productivity contributes to higher household income, improved food security, and the ability to meet the socio-economic needs of the family. Meanwhile, farm efficiency enables farmers to obtain greater profits through reduced production costs and optimal utilization of local resources.

These findings support the study by Usni (2025), which states that IFSs can improve farmers' welfare through business diversification, production efficiency, and strengthened household economic resilience. In addition, farm diversification also helps reduce economic risks caused by dependence on a single commodity (Suprianto et al., 2025). This study shows that farming households implementing crop–beef cattle integration have better economic stability compared to non-integrated farmers. The welfare improvement observed in this study is not solely driven by higher income but also by greater household resilience. IFSs provide multiple production outputs, including

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crops, livestock, manure, and feed resources, which reduce vulnerability to market fluctuations, crop failure, and climate-related risks. As a result, farmer households are better able to maintain food availability, stabilize income, and sustain their livelihoods under suboptimal land conditions.

H8, H9: Development of an Integrative Model for Farmer Empowerment and Optimization of Beef Cattle Management

The results of the study showed that farmer empowerment and the optimization of beef cattle management are key components in the development of an integrative model of an IFS based on suboptimal land in Minahasa. The model emphasizes that the success of beef cattle farming is not only determined by technical aspects of livestock management but is also influenced by farmers' capacity, institutional support, technology adoption, and multi-stakeholder involvement.

Farmer empowerment strengthens farmers' ability to access information, technology, financial resources, and market opportunities, thereby increasing their capacity to manage IFSs effectively. At the same time, the optimization of beef cattle management through improved feeding practices, animal health management, reproductive performance, and waste utilization enhances the productivity and profitability of livestock enterprises. The combination of farmer empowerment and improved livestock management creates a strong foundation for sustainable integrated farming development. Therefore, the proposed integrative model provides a practical framework for enhancing productivity, efficiency, and farmer welfare while promoting the long-term sustainability of agricultural systems on suboptimal land in Minahasa Regency.

Based on the empirical findings obtained from the regression analyses and the theoretical framework developed in this study, an integrative model was formulated to illustrate the interrelationships among farmer empowerment, optimization of beef cattle management, and the implementation of IFS on suboptimal land. The model synthesizes the statistically significant relationships identified in this research into a practical framework for sustainable agricultural development.

Figure 2. An Integrative Model of Farmer Empowerment and Optimization of Beef Cattle Management in an IFS on Suboptimal Land

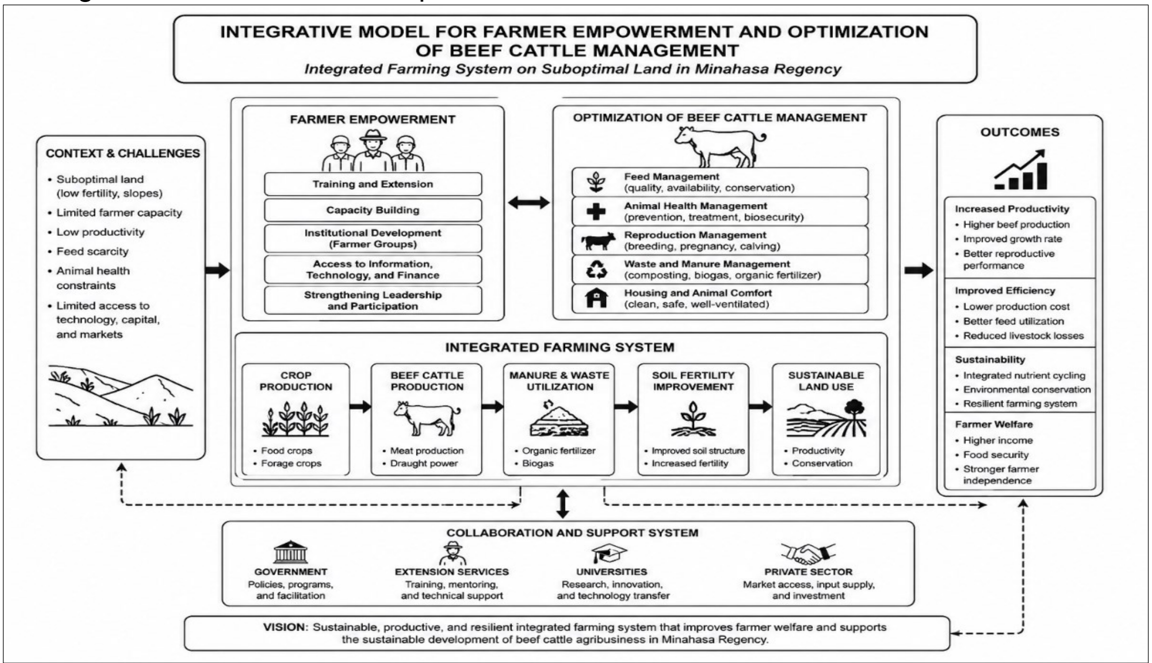

Figure 2 illustrates the proposed integrative model developed from the empirical findings of this study. The model demonstrates how strengthening farmer empowerment and optimizing beef cattle management collectively support sustainable IFS implementation, ultimately improving productivity, farming efficiency, and farmers' welfare under suboptimal land conditions. These conditions lead to low agricultural and livestock productivity, making it necessary to adopt an empowerment approach that can comprehensively enhance farmers' capacities.

Strengthening farmers' capacity through training, extension services, and institutional development has been proven to improve farmers' ability to adopt integrated farming innovations. Empowerment is carried out through the enhancement of technical, managerial, and entrepreneurial skills; strengthening farmer and livestock groups; improving access to technology and financing; and increasing farmers' participation and leadership in agribusiness development.

In addition to farmer empowerment, the optimization of beef cattle management is also a key factor in this integrative model. Optimization is carried out through improvements in feed management, animal health, reproduction, waste management, and housing systems. The provision of high-quality and sustainable feed can improve livestock growth and productivity. Animal health management through disease prevention, treatment, vaccination, and biosecurity can reduce mortality rates and improve business efficiency.

On the other hand, the utilization of livestock waste into organic fertilizer and biogas provides added value while supporting environmentally friendly agriculture. Crop–livestock integration creates a mutually beneficial relationship, where crop residues are used as animal feed and livestock waste is utilized to improve soil fertility.

The findings of this study support the research by Jones et al. (2022) and Ryschawy et al. (2022), which emphasize that agroecology-based livestock systems require the integration of technology, farmer empowerment, and local institutions to achieve sustainable farm operations. In addition, improving farmers' capacity and the application of appropriate technologies have been proven to enhance the productivity and sustainability of smallholder livestock enterprises (Agatha & Sjaf, 2022; Nengsi, 2025).

This integrative model also highlights the importance of collaboration among the government, extension workers, universities, and the private sector in supporting the development of beef cattle agribusiness that is productive, efficient, sustainable, and capable of continuously improving farmers' welfare.

Why IFSs Improve Productivity, Farming Efficiency, and Farmers' Welfare Under Suboptimal Land Conditions

The positive effects of IFSs on farm productivity, farming efficiency, and farmers' welfare can be explained through ecological, economic, and institutional mechanisms. According to Sustainable Agriculture Theory, integrated farming creates mutually beneficial interactions between crop and livestock enterprises by recycling resources within the farming system. Crop residues are utilized as livestock feed, while livestock manure is returned to agricultural land as organic fertilizer, improving nutrient cycling, soil fertility, and resource-use efficiency. These ecological processes are particularly important under suboptimal land conditions, where soil fertility and external production inputs are limited (Oenema & Oenema, 2022; Palsaniya et al., 2022).

From an economic perspective, crop–livestock integration reduces production costs by substituting commercial feed and inorganic fertilizers with locally available resources.

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This internal resource recycling improves technical efficiency while maintaining or increasing production levels, consistent with the positive effects of crop–livestock integration on farm productivity and farming efficiency identified in this study. These findings are in line with Nayak et al. (2023), who reported that integrated farming systems achieve higher productivity and efficiency through improved resource allocation and lower production costs.

The benefits of IFSs extend beyond productivity by strengthening farmers' resilience and welfare. Income diversification from both crop and livestock enterprises reduces dependence on a single commodity, stabilizes household income, and enhances farmers' capacity to cope with market and climate-related risks. This finding supports Sustainable Livelihood Theory, which emphasizes that diversified livelihood strategies improve household resilience and long-term welfare.

The effectiveness of IFSs is further reinforced by farmer empowerment and institutional support. Access to extension services, farmer organizations, technology, financing, and market information enhances farmers' capacity to adopt innovations and sustain integrated farming practices. Consistent with Community Empowerment Theory and previous studies (Lainawa et al., 2024; Purnomo et al., 2023; Roessali et al., 2022), these findings indicate that sustainable IFS development depends not only on technical improvements but also on strong institutional support and farmer participation.

Overall, the findings demonstrate that the success of IFSs under suboptimal land conditions results from the combined effects of ecological resource recycling, cost efficiency, income diversification, farmer empowerment, and institutional strengthening. Together, these mechanisms improve productivity, farming efficiency, and farmers' welfare while supporting sustainable agricultural development in Minahasa Regency.

CONCLUSION

This study concludes that the development of IFSs based on suboptimal land in Minahasa has strong potential to improve farm productivity, operational efficiency, and farmers' welfare through the integration of crops and beef cattle.

Technical, socio-economic, and institutional factors were proven to have a positive influence on the implementation of IFSs. Farmers' abilities in feed management, utilization of agricultural and livestock waste, and adaptation to suboptimal land conditions are key determinants of farm success. In addition, education, farming experience, access to capital, and institutional support such as farmer groups, extension services, and local government also contribute to the adoption of integrated farming innovations.

Crop–beef cattle integration provides various benefits, including the use of crop residues as livestock feed and the application of organic fertilizer from livestock waste to improve soil fertility, reduce production costs, and strengthen resource sustainability. This system also enhances household income, food security, and rural economic stability.

The study produces an empowerment-based model supported by extension services, training, access to financing, and local technology utilization. This study contributes to the literature by proposing an empirically supported integrative model that explains the relationships among farmer empowerment, beef cattle management optimization, IFS implementation, productivity, efficiency, and farmers' welfare under suboptimal land conditions.

LIMITATION

This study has several limitations, including limited research coverage, the use of respondent perception-based data, and a greater focus on technical, socio-economic, and institutional aspects. Ecological aspects, as well as the utilization of digital technology, smart farming, and IoT in IFSs, have not been thoroughly analyzed. Future research is recommended to develop longitudinal approaches and dynamic system modeling to analyze the long-term sustainability of IFSs.

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DECLARATION OF CONFLICTING INTERESTS

The authors declare that there are no potential conflicts of interest related to the research, authorship, and/or publication of this article.

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