Sustainable Rice Systems in Rural Communities: Integrating Demographic, Agricultural, Consumption, and Waste Management Insights

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Sustainable Rice Systems in Rural Communities: Integrating Demographic, Agricultural, Consumption, and Waste Management Insights

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Abstract: *This study examines the integration of circular economy principles in rice production systems within the Caraga Region, Philippines. Through a mixed-methods approach involving 616 rice farmers across five provinces, current practices and the potential for circular economy adoption were assessed. Findings indicate modest yield improvements averaging 0.15 MT/ha/year from 2018-2023, alongside significant challenges in waste management,, with 73% of farmers resorting to burning rice straw. The Circular Economy Contribution Index (CECI) stands at 0.68, reflecting moderate adoption of circular principles. Economic analysis suggests that better utilization of rice by-products could potentially yield an additional income of PHP 14,700/ha/year. System dynamics modeling forecasts that enhanced integration of circular economy practices could annually increase the sustainability index by 0.05 while reducing costs by 15%. This research underscores the potential benefits and challenges of transitioning towards more sustainable and economically viable rice production systems in the region.*

Keywords: Circular Economy; Rice Production; Waste Valorization;

1. INTRODUCTION

Rice production is a cornerstone of food security and rural livelihoods in the Philippines, providing nearly half of the population's calorie intake. In the Caraga Region, rice farming represents not only a source of sustenance but also a cultural heritage and economic foundation for rural communities. However, conventional rice production systems face mounting challenges from climate change, resource depletion, market volatility, and waste management issues [1,2,3]. The concept of circular economy offers a promising framework for addressing these challenges by redesigning agricultural systems to minimize waste, regenerate natural systems, and create sustainable value chains. Unlike the traditional linear "take-make-dispose" model, circular economy approaches in agriculture emphasize resource efficiency, waste valorization, and closed-loop systems that mimic natural cycles [4,5,6,7]. Recent studies have demonstrated the potential for circular economy implementation in Southeast Asian rice production systems, highlighting both technological innovations and economic benefits [8,9]. Recent research underscores the importance of transitioning from linear to circular models in rice production, where resource efficiency, waste minimization, and nutrient cycling are prioritized [10,11]. Comparative studies across Asia demonstrate that integrating circular economy principles can yield significant economic and environmental benefits.

Despite growing interest in circular economy principles globally, their application to rice production systems in the Philippines remains limited and fragmented. Previous studies have examined sustainable rice practices [12], agroecological models [13], and challenges faced by smallholder farmers [14], but few have comprehensively assessed the potential for circular economy integration in rice systems, particularly in the Caraga Region [15,16,7] emphasized the importance of resource efficiency and waste valorization in rice-based agricultural systems, while [9] provided case studies demonstrating successful circular economy implementation in Philippine rice production contexts.

This study addresses this gap by developing an integrated analytical framework to assess and enhance circular economy principles in rice production systems across the Caraga Region. Specifically, the research aims to: (1) evaluate current rice production practices, consumption patterns, and waste management approaches in the Caraga Region; (2) develop and apply metrics for assessing circular economy integration in rice production systems; (3) identify barriers and enablers for circular economy adoption among rice farmers; (4) quantify the economic, environmental, and social benefits of circular approaches; and (5) propose intervention strategies for enhancing circular economy integration in rice systems.

2. METHODOLOGY

2.1 Research Design

This study employed a mixed-methods approach combining quantitative and qualitative research methods to develop a comprehensive understanding of rice production systems and circular economy potential in the Caraga Region. The research design included: 1) cross-sectional survey using a structured questionnaire administered to rice farmers to collect data on production practices, consumption patterns, waste management, and socioeconomic characteristics; 2) semi-structured interviews through in-depth interviews with key stakeholders, including farmers, local government officials, agricultural extension workers, and private sector representatives; 3) field observations through direct observations of rice production practices, waste management approaches, and circular economy initiatives; 4) secondary data analysis: Analysis of existing data on rice production, prices, and consumption from government agencies and research institutions; 5) system dynamics modeling through the development of a system dynamics model to simulate the impacts of circular economy integration on rice production systems.

2.2 Sampling and Data Collection

2.2.1 Sampling Design

A multi-stage sampling approach was employed to select respondents for the cross-sectional survey (Fig. 1): 1) Stage 1: Purposive selection of all five provinces in the Caraga Region (Agusan del Norte, Agusan del Sur, Surigao del Norte, Surigao del Sur, and Dinagat Islands); 2) Stage 2: Random selection of municipalities within each province, with probability proportional to rice production area; 3) Stage 3: Random selection of barangays (villages) within each municipality; 4) Stage 4: Systematic random sampling of rice farmers within each barangay. The final sample consisted of 616 rice farmers distributed across the five provinces as follows: Agusan del Norte: 173 respondents; Agusan del Sur: 325 respondents; Surigao del Norte: 51 respondents; Surigao del Sur: 53 respondents; Dinagat Islands: 14 respondents. For the semi-structured interviews, purposive sampling was used to select 45 key stakeholders, including: 20 rice farmers (selected based on farm size, production system, and adoption of circular practices); 10 local government officials (agricultural officers and planning officers); 8 agricultural extension workers; and 7 private sector representatives (rice millers, traders, and input suppliers).

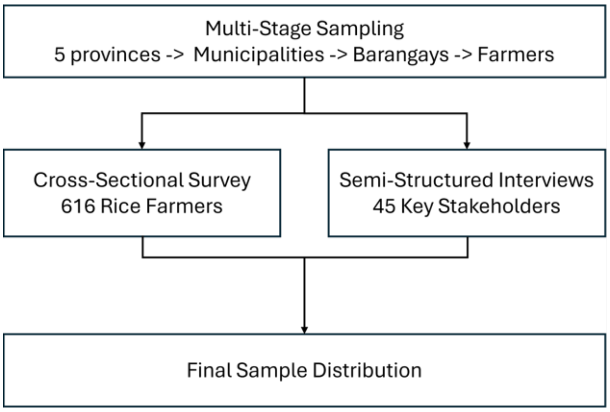

Fig. 1. Sampling Approach of the Study

2.2.2 Data Collection Methods

Data collection was conducted from August to December 2024 using the following methods [17]. A comprehensive structured questionnaire was developed to collect data on demographic and socioeconomic characteristics, rice production practices and inputs, rice yields and income (2018-2023), consumption patterns and market participation, waste generation and management practices, awareness and adoption of circular economy practices, and barriers and enablers for circular economy adoption. Additionally, a semi-structured interview guide was developed to explore perceptions of circular economy concepts and principles, experiences with circular practices in rice production, challenges and opportunities for circular economy integration, policy and institutional factors affecting circular economy adoption, and potential intervention strategies for enhancing circular economy integration.

The research also employed a structured observation checklist to document rice production practices and technologies, waste management approaches and infrastructure, existing circular economy initiatives and their implementation, and environmental conditions and resource use patterns. Secondary data collection was conducted to gather information on rice production, prices, and consumption from 2018 to 2023 from sources including the Philippine Statistics Authority (PSA), Department of Agriculture (DA), Local government units (LGUs), research institutions, and previous studies.

2.3 Analytical Framework

2.3.1 Circular Economy Assessment Framework

The assessment framework for circular economy in rice production is strengthened by incorporating multi-indicator approaches, such as those proposed by [10], and benchmarking resource efficiency and sustainability indicators as demonstrated by [11]. This enables a more holistic evaluation of circularity and sustainability.

A comprehensive framework (Fig. 2) was developed to assess circular economy integration in rice production systems, comprising five key: Agri-waste Management (AW), which includes practices related to the management of rice straw, husks, and other by-products; Organic Production (OP), focusing on the use of organic inputs, reduced chemical use, and agroecological practices; Bio-conversion (BC), involving the transformation of agricultural waste into valuable products; Business Models (BM), encompassing circular business approaches and value chain integration; and Value Integration (VI), which addresses the integration of environmental, social, and economic values. Each dimension was assessed using multiple indicators, scored on a scale of 0 to 1, where 0 represents no circular economy integration and 1 represents full integration.

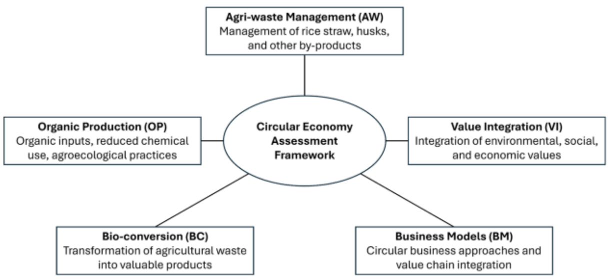

Fig. 2. Circular Economy Assessment Framework

2.3.2 Circular Economy Contribution Index (CECI)

The Circular Economy Contribution Index (CECI) was calculated as a weighted average of the five dimensions:

$$CECI = \omega_{AW} \cdot AW + \omega_{OP} \cdot OP + \omega_{BC} \cdot BC + \omega_{BM} \cdot BM + \omega_{VI} \cdot VI$$

In this equation, w_{AW}, w_{OP}, w_{BC}, w_{BM}, and w_{VI} are the weights assigned to each dimension, while AW, OP, BC, BM, and VI are the scores for each dimension. The weights were determined through an Analytic Hierarchy Process (AHP) involving expert consultations, resulting in: $\omega_{AW} = 0.25$; $\omega_{OP} = 0.20$, $\omega_{BC} = 0.20$, $\omega_{BM} = 0.15$, and $\omega_{VI} = 0.20$. Recycling efficiency (η) was calculated as the ratio of recycled agricultural waste to total agricultural waste generated: $\eta = \frac{W_r}{W_t}$, where W_r is the amount of agricultural waste recycled or repurposed and W_t is the total amount of agricultural waste generated. Alignment with the national circular economy framework was assessed using the Circular Economy Alignment index: $CEA = \frac{1}{3} \cdot (E + B + G)$, where E is the alignment score for environmental dimensions, B is the alignment score for business and technology dimensions, and G is the alignment score for governance dimensions. The economic value of circular approaches was calculated using: $EV = \sum_{i=1}^{n}(Q_i x P_i) - C$, where EV is the economic value, Q_i is the quantity of product i derived from agricultural waste, P_i, P is the market price of the product i, C is the cost of processing and marketing, and n is the number of products derived from agricultural waste. A system dynamics model was developed to simulate the impacts of circular economy integration on rice production systems [18]. The model included production, waste management, economic, environmental, and social subsystems. It was used to simulate three scenarios: baseline scenario (continuation of current trends), enhanced circular economy scenario (moderate improvements in circular economy integration), and integrated intervention scenario (comprehensive interventions for circular economy enhancement).

2.4 Data Analysis

Quantitative data were analyzed using descriptive statistics including means, frequencies, and percentages to characterize rice production systems, waste management practices, and circular economy adoption; trend analysis to examine rice production, yields, and prices from 2018 to 2023; correlation and regression analysis to investigate relationships between variables and factors influencing circular economy adoption; economic analysis including cost-benefit analysis, return on investment (ROI), and payback period calculations for circular economy initiatives; and system dynamics simulation to project impacts under different scenarios. Qualitative data from interviews and observations were analyzed using thematic analysis to identify key themes and patterns related to circular economy perceptions, barriers, enablers, and potential interventions; content analysis for systematic coding and categorization of interview transcripts; case study analysis for in-depth examination of successful circular economy initiatives; and SWOT analysis to assess strengths, weaknesses, opportunities, and threats for circular economy integration. The findings from quantitative and qualitative analyses were integrated through triangulation to cross-verify findings from different data sources; complementarity to use qualitative findings to explain and contextualize quantitative results; development to use qualitative insights to refine quantitative measures and models; and expansion to broaden the scope of inquiry through different methods.

3. RESULTS AND DISCUSSION

3.1 Demographic and Socioeconomic Characteristics

The survey respondents (n=616) had the following characteristics: Mean age of 52.3 years (SD=13.7), with 28% under 45 years, 42% between 45-60 years, and 30% over 60 years; 68% male and 32% female; education levels consisting of 42% elementary, 38% high school, 15% vocational/college, and 5% with no formal education; mean household size of 4.8 members (SD=2.1); mean farm size of 1.8 hectares (SD=1.3), with 72% having less than 2 hectares; mean farming experience of 23.5 years (SD=14.2); and land tenure distribution of 58% owner-operators, 25% tenants, 12% leaseholders, and 5% other arrangements. These demographic characteristics influence farmers' capacity to adopt circular economy practices, with education level, farm size, and land tenure being particularly important factors.

3.2 Rice Production Trends (2018-2023)

Analysis of rice production data from 2018 to 2023 revealed the following trends: Total rice area in Caraga increased from 159,842 hectares in 2018 to 163,275 hectares in 2023, representing a modest annual growth rate of 0.42%; average yield increased from 3.85 MT/ha in 2018 to 4.60 MT/ha in 2023, with an average annual increase of 0.15 MT/ha ($p<0.05$); total production increased from 615,392 MT in 2018 to 751,065 MT in 2023, with an average annual growth rate of 4.1%; average cropping intensity increased from 1.3 in 2018 to 1.5 in 2023, indicating more intensive land use; and chemical fertilizer use decreased by 8% from 2018 to 2023, while organic fertilizer use increased by 15%. The modest yield increases were primarily attributed to improved varieties and farming practices, particularly in areas with good irrigation infrastructure. However, areas with poor irrigation showed stagnant or declining yields, highlighting the importance of water management for sustainable rice production.

3.3 Consumption Patterns and Market Dynamics

Analysis of rice consumption and market data revealed: Average per capita rice consumption in Caraga was 118 kg/year, slightly higher than the national average of 109 kg/year; estimated price elasticity of demand was -0.76, indicating that a 10% increase in price leads to a 7.6% decrease in quantity demanded; estimated income elasticity was 0.23, indicating that rice is a necessity good with demand increasing modestly with income; seasonal price variations showed rice prices peaked during April-June (lean months) at approximately PHP 48.5/kg and fell during October-December (harvest months) at approximately PHP 38.2/kg; market participation data indicated 62% of farmers were net buyers of rice at some point during the year, highlighting complex producer-consumer dynamics; and marketing channels consisted of 45% selling to traders, 30% to cooperatives, 15% directly to consumers, and 10% to government procurement. These findings highlight the importance of stable markets and fair prices for ensuring both food security and farmer livelihoods in the rice sector.

3.4 Waste Generation and Management Practices
The study quantified agricultural waste generation and management practices: Rice hull generation was approximately 1,469 kg/ha/year, totaling about 235,000 MT annually in the Caraga Region, while rice straw generation was approximately 7,478 kg/ha/year, totaling about 1.2 million MT annually. Current management practices for rice straw include 73% burned in the field, 18% incorporated into the soil, 5% used as animal feed, 3% used for mushroom production, and 1% used for other purposes. For rice hull, current management practices consisted of 65% unused/burned, 22% used as fuel for drying, 8% used for composting, 5% sold to other users, and 0% used for biochar production. The calculated recycling efficiency (η) was 0.14, indicating that only 14% of agricultural waste was being recycled or repurposed, highlighting significant opportunities for improvement.

3.5 Circular Economy Integration Assessment
The assessment of circular economy integration using the CECI framework yielded the following results: Agri-waste Management (AW) received a score of 0.85, indicating relatively strong waste management awareness but limited implementation of advanced practices; Organic Production (OP) scored 0.72, reflecting moderate adoption of organic inputs and reduced chemical use; Bio-conversion (BC) scored 0.45, indicating limited transformation of agricultural waste into valuable products; Business Models (BM) scored 0.58, showing moderate development of circular business approaches; and Value Integration (VI) scored 0.79, reflecting good integration of environmental, social, and economic values. The overall Circular Economy Contribution Index (CECI) was calculated as: CECI = 0.25 × 0.85 + 0.20 × 0.72 + 0.20 × 0.45 + 0.15 × 0.58 + 0.20 × 0.79 = 0.68. This indicates a moderate level of circular economy integration in rice production systems in the Caraga Region, with strengths in waste management awareness and value integration, but weaknesses in bioconversion and business models. The Circular Economy Alignment (CEA) with the national framework was calculated as:

$$CEA = \frac{1}{3} \cdot (0.85 + 0.68 + 0.60) = 0.71.$$

This indicates good alignment with national policies, particularly in environmental dimensions (0.85), moderate alignment in business and technology dimensions (0.68), and adequate alignment in governance dimensions (0.60).

3.6 Economic Valuation of Circular Approaches
The economic analysis of circular economy approaches revealed significant potential for value creation: Biochar from rice hulls showed potential revenue of PHP 8,500/ha/year, with production costs of PHP 3,200/ha/year, resulting in net income of PHP 5,300/ha/year; organic fertilizer from rice straw demonstrated potential revenue of PHP 6,200/ha/year, with production costs of PHP 2,800/ha/year, resulting in net income of PHP 3,400/ha/year; and mushroom production using rice straw indicated potential revenue of PHP 12,000/ha/year, with production costs of PHP 6,000/ha/year, resulting in net income of PHP 6,000/ha/year. Community-based enterprises for processing agricultural waste showed an average return on investment (ROI) of 35% over three years, with a payback period of 2.1 years. Increasing the recycling efficiency (η) from the current 0.14 to 0.50 could generate an additional income of PHP 14,700/ha/year for farmers, representing a significant economic opportunity. Findings from [11] highlight the potential for improved resource efficiency and waste valorization in rice systems, aligning with the nutrient cycling and waste management strategies advocated by [10]. Integrating these approaches can enhance both the environmental and economic performance of rice production in the Caraga Region.

3.7 System Dynamics and Integration Analysis
The system dynamics model projected the following impacts under different scenarios: in the baseline scenario, the sustainability index would increase by 0.02 over five years, with minimal improvements in economic, environmental, and social outcomes; while in the enhanced circular economy scenario, the sustainability index would increase by 0.05 annually, with 15% reduction in production costs, 12% increase in farm income, 30% reduction in greenhouse gas emissions, and 25% increase in soil organic matter. The correlation analysis revealed a strong positive correlation between circular economy adoption and economic outcomes ($r = 0.68$, $p<0.01$), a strong positive correlation between circular economy adoption and environmental outcomes ($r = 0.72$, $p<0.01$), and a moderate positive correlation between circular economy adoption and social outcomes ($r = 0.54$, $p<0.01$). Age was a significant factor in circular economy adoption, with younger farmers (<45 years) adopting circular practices 28% more frequently than older farmers (>60 years).

3.8 Barriers and Enablers for Circular Economy Adoption
The study identified several barriers and enablers for circular economy adoption: Economic barriers to circular economy adoption included high initial investment costs cited by 82% of respondents, limited access to finance reported by 75%, uncertain markets for products derived from agricultural waste mentioned by 68%, and

opportunity costs cited by 55%. Institutional barriers encompassed policy gaps mentioned by 62%, weak coordination among different stakeholders cited by 70%, limited institutional capacity reported by 65%, and regulatory constraints mentioned by 58%. Social and cultural barriers consisted of risk aversion expressed by 72%, traditional mindsets cited by 65%, limited awareness reported by 60%, and collective action challenges mentioned by 55%. Technical enablers included existing knowledge base about resource conservation and recycling, adaptable technologies available for local conditions, ongoing research on circular approaches in agriculture, and demonstration effects from successful examples in similar contexts. Economic enablers comprised potential cost savings through circular approaches, opportunities for creating additional value from agricultural by-products, growing demand for sustainably produced agricultural products, and emerging financial mechanisms supporting circular initiatives. Institutional enablers included the existence of a national framework for circular economy, growing support from LGUs for sustainable agriculture, the presence of farmer organizations and cooperatives, and emerging partnerships with the private sector and research institutions. Social and cultural enablers encompassed growing environmental awareness among farmers, greater openness to innovation among younger farmers, strong community ties and social capital, and cultural values aligned with sustainability principles.

Barriers such as limited policy support, fragmented value chains, and lack of awareness, as identified by both [11] and [10], must be addressed through multi-level governance, stakeholder engagement, and targeted education initiatives.

3.9 Intervention Strategies for Enhancing Circular Economy Integration

Based on the analysis of barriers and enablers, the study identified several intervention strategies for enhancing circular economy integration in rice production systems: Technical interventions included providing training and technical assistance on circular practices, developing and adapting appropriate technologies for small-scale operations, establishing demonstration farms showcasing circular approaches, and strengthening agricultural extension services focused on circular economy. Economic interventions comprised providing grants, loans, and subsidies for circular economy initiatives, creating and strengthening markets for products derived from agricultural by-products, supporting the development of circular value chains through processing, certification, and marketing, and implementing economic incentives, such as tax breaks and subsidies, for circular economy initiatives. Institutional interventions involved aligning agricultural policies with the national circular economy framework, developing and enforcing regulations supporting circular practices, such as restrictions on open burning of rice straw, establishing platforms for coordination and collaboration among different stakeholders, and developing certification systems for products derived from agricultural by-products. Social and cultural interventions included conducting awareness campaigns on the benefits of circular economy practices, promoting farmer-to-farmer learning and exchange of experiences, supporting community-based initiatives for collective action on circular economy, and developing age-sensitive approaches to leverage the greater openness to innovation among younger farmers. The study identified three integrated intervention packages with high potential impact: community-based bio-conversion hubs to establish community-level facilities for processing rice by-products into valuable products, supported by training, market linkages, and policy incentives; circular rice-based farming systems to promote integrated farming systems that optimize resource flows and minimize waste, combining rice production with livestock, aquaculture, and horticulture; and digital platforms for circular value chains to connect farmers, processors, and consumers in circular value chains, providing information, facilitating transactions, and ensuring traceability. System dynamics modeling projected that implementing these integrated intervention packages could increase the sustainability index by up to 0.08 annually, significantly exceeding both the baseline and enhanced circular economy scenarios.

4. CONCLUSIONS AND RECOMMENDATIONS

This study has developed and applied a comprehensive framework for assessing and enhancing circular economy integration in rice production systems in the Caraga Region, Philippines. The research has generated several key insights:

Rice production in the Caraga Region has shown modest yield increases from 2018 to 2023 (0.15 MT/ha/year), but significant challenges remain in terms of resource efficiency and waste management. Current waste management practices are predominantly linear, with 73% of farmers burning rice straw and 65% of rice husks being unused or burned, resulting in a low recycling efficiency (η) of 0.14. The Circular Economy Contribution Index (CECI) of 0.68 indicates moderate adoption of circular principles, with the strongest performance in agri-waste management awareness (0.85) and value integration (0.79), but weaknesses in bioconversion (0.45) and business models (0.58). Economic analysis demonstrates significant potential for value creation through circular approaches, with improved valorization of rice by-products potentially generating additional income of PHP 14,700/ha/year. System dynamics modeling projects that enhance circular economy integration could increase the sustainability index by 0.05 annually, reducing costs by 15% and increasing income by 12%. Multiple barriers to circular economy adoption exist, including limited knowledge and skills, high initial investment costs, policy gaps, and traditional mindsets, but also several enablers, such as cost-saving potential, growing environmental awareness, and support from local government units. Age is a significant factor in circular economy adoption, with younger farmers (<45 years) adopting circular practices 28% more frequently than older farmers (>60 years). Integrated intervention packages combining technical, economic, institutional, and social approaches have the potential to significantly enhance circular economy integration and improve sustainability outcomes. This research contributes to the growing body of knowledge on circular economy in agriculture by providing a comprehensive assessment framework, empirical evidence on current practices and potential benefits, and practical intervention strategies for enhancing circular economy integration in rice production systems.

Based on the findings of this study, the following recommendations are proposed for different stakeholders: For farmers and farmer organizations, recommendations include establishing community-based facilities for processing agricultural by-products, forming cooperatives or associations for collective action on circular economy initiatives, participating in training and capacity-building programs on circular practices, documenting and sharing traditional knowledge and innovations related to resource efficiency, and engaging younger farmers into decision-making processes to leverage their greater openness to innovation. For local government units, recommendations include developing local ordinances supporting circular economy practices in agriculture, investing in community-scale infrastructure for bioconversion and waste valorization, integrating circular economy principles into local agricultural development plans, providing incentives for farmers adopting circular practices, and facilitating market linkages for products derived from agricultural by-products. For national government agencies, recommendations include aligning agricultural policies with the national circular economy framework, increasing research and development funding for circular agricultural technologies, developing certification systems for products derived from agricultural by-products, incorporating circular economy principles into agricultural extension programs, and creating financial mechanisms to support investments in circular agriculture. For research and academic institutions, recommendations include conducting longitudinal studies to track the long-term impacts of circular economy integration, developing and refining metrics for assessing circular economy in agricultural systems, investigating the potential of digital technologies to enhance circular economy implementation, conducting life cycle assessments of different circular approaches, and expanding research to other regions and farming systems. For the private sector and industry, recommendations include investing in technologies for processing agricultural by-products, developing market channels for products derived from agricultural waste, establishing partnerships with farmer organizations for sustainable sourcing, incorporating circular economy principles into corporate sustainability strategies, and supporting knowledge transfer and capacity building in rural communities. This study has several limitations that should be acknowledged: the one-year timeframe for primary data collection may not capture long-term trends and seasonal variations, the regional focus limits the generalizability of findings to other rice-producing areas, the economic valuation relies on current market prices, which may fluctuate over time, and the system dynamics model simplifies complex socio-ecological interactions. Future research should address these limitations through longitudinal studies tracking circular economy integration over multiple years, comparative analyses across different regions and farming systems, more detailed life cycle assessments of circular approaches, exploration of digital technologies to enhance circular economy implementation, investigation of policy mechanisms to scale up successful circular practices, and refinement of circular economy metrics specific to agricultural systems. By building on this research, future studies can contribute to the ongoing transformation of agricultural systems toward greater sustainability, resilience, and circularity.

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