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A Multi-Stakeholder Collaboration Model in Sustainable Agricultural Waste Management: A Case Study Supporting Organic Farming in Bali

I Nengah Muliarta[1,2]*, Ni Ketut Sri Rahayu[1]

[1]Agrotechnology Study Program, Faculty of Agriculture, Science, and Technology, Universitas Warmadewa, Bali, Indonesia
[2]Master of Agricultural Science Study Program, Postgraduate Faculty, Warmadewa University-Bali, Indonesia

*Correspondence: nengahmuliarta@email.com

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ABSTRACT: Agricultural waste management in Bali faced complex challenges due to various obstacles in the transition to sustainable organic agriculture. This research focused on collaborative models among stakeholders involved in agricultural waste management. The aim of this research was to explore collaborative models for stakeholders in agricultural waste management that aligned with the journey towards organic farming. This research used a qualitative descriptive method, including a literature review and field observations to identify challenges and opportunities. The results indicated that the Sustainable Organic Circle Model could improve waste management efficiency, reduce greenhouse gas emissions, and enhance soil fertility. The issue of agricultural waste in Bali (rice straw, horticultural waste, livestock waste) was the most critical, but at the same time, it had great potential for sustainability, particularly through composting, animal feed, and biogas production. Current practices were still dominated by crop residue burning due to a lack of knowledge, facilities, and financial constraints. The Integrated Farming System Program and collaboration among stakeholders (including government, NGOs, and academics) were ongoing, but still faced challenges such as limited farmer knowledge and unintegrated policies.

KEYWORDS: Agricultural sustainability; agricultural waste; management; organic farming; cooperation model

1. Introduction

Agriculture contributed substantially to the economy of Bali yet faced serious obstacles, the most typical of which was the handling of agricultural waste during the transition to organic farming. It accounted for 15% of Bali's gross domestic product in 2020, making it the second-largest sector, following accommodation, food, and beverages at 18% [1]. Even in the use, processing, and consumption of agricultural products, the wastes generated were often handled through harsh methods, either by burning or by disposal. These practices polluted the air and soil and at the same time wasted the economic potential of the waste [2]. Addressing this issue depended on the creation of a joint and integrated approach to managing agricultural waste for the conversion to organic farming in Bali.

The condition in Bali showed a strong dichotomy between traditional farming and the much-needed shift to more sustainable organic farming. After five years of organic farming in Tabanan, Bali, the soil quality did not fall below sustainability standards even without excessive inputs [3]. In contrast, conventional farming relied on chemical fertilizers and pesticides, which harmed soil quality and ecosystems [4]. Although there was great potential for organic farming in Bali, previous research did not sufficiently explore collaborative models involving all stakeholders in agricultural waste management. Most existing studies focused more on technical aspects of organic farming, while the role of collaboration among stakeholders was often neglected. Therefore, further research on collaborative models was essential to identify the best strategies applicable within the local Balinese context.

The shift from conventional farming to biological methods was not easy; many farmers remained attached to age-old practices due to a lack of knowledge, outdated technology, and insufficient support from the government and related organizations [5]. There was also a significant productivity gap, with organic farming being 29% to 44% less productive than conventional methods. Food crops experienced a yield gap of about 25%, while cereals maintained an approximate productivity gap of 30% [6]. Organic farming in Bali showed strong potential for sustainability, but several hurdles remained: limited sources of organic fertilizers, scarce irrigation water, financial constraints affecting certification, and fluctuating market demand [7].

This research was challenged to design a collaborative framework to co-manage agricultural waste in support of the transition to organic agriculture in Bali. The stakeholders integrated into this model included farmers, government officials, academics, and civil society—those who could create synergies to promote awareness and understanding of sustainable waste management practices. Another important aspect was how this collaborative framework aligned with ground realities and addressed the opportunities and challenges likely to arise during the transition. As Gudadur et al. [8] pointed out, cooperation offered an effective means of managing agricultural waste by turning waste into wealth through composting, biochar production, and bio-based energy generation—initiatives that reduced greenhouse gas emissions and enhanced investment opportunities.

In practice, the gap between understanding and application became evident. In Bali, despite studies and initiatives promoting organic farming, many farmers hesitated to abandon conventional methods. This hesitation stemmed from factors such as a lack of credible information, doubts about the economic benefits of organic farming, and concerns about potential economic disruption [9]. Ineffective policies and programs further inhibited farmers' ability to adopt organic farming. Many farmers in Buleleng Regency, Bali, did not perceive organic farming positively due to insufficient government support, challenging market conditions, internal organizational issues, and inefficiency within Subak institutions [7]. Even though the government implemented development programs to promote sustainable agriculture, these initiatives often failed to address farmers' real needs on the ground [2]. Thus, research on policy effectiveness needed to be strengthened to better support future adoption of organic farming.

Cooperative models proved effective in agricultural waste management, especially in rural areas and smallholder farming communities [10]. The integration of multiple stakeholders in cooperative models increased productivity, income, and logistics efficiency, and also strengthened smallholder farmers' bargaining positions in the market [11]. This collaborative approach also opened opportunities for innovation, such as integrating agricultural waste with nanomaterials for more sustainable environmental solutions [12]. Overall, cooperative models offered an adaptive and inclusive framework for agricultural waste management, with strong potential to improve organic farming yields through stakeholder synergies [10].

A joint approach to agricultural waste management was expected to be highly beneficial in addressing these challenges. This model featured a multi-pronged approach, including farmer training and education, proficiency in environmentally sound waste management technologies, and partnerships between farmers and research institutions to encourage innovations that enhanced productivity and sustainability [13]. In addition, collaboration among government, the private sector, and civil society was needed to nurture an ecosystem supportive of organic farming [14].

Proper agricultural waste management was essential not only for minimizing environmental impacts but also for maximizing resource-use efficiency and promoting sustainability in agriculture [15]. By converting agricultural waste into usable resources, farmers reduced production costs and gained additional income [16]. This justified the integration of waste management techniques with organic farming practices. This article explored collaborative models for agro-waste management and the transition to organic farming in Bali. It aimed to identify challenges and opportunities, and more importantly, proposed measures to improve the efficiency of agricultural waste management and to enhance transition pathways toward sustainable farming. With the right strategies in place, Bali could become a beacon for other regions in Indonesia in managing agricultural waste and transforming it into sustainable organic farming. To achieve this goal, a collaborative model was needed involving all stakeholders, including farmers, government, academics, and civil society.

2. Materials and Methods

2.1. Study area.

The research location for this study was Bali, Indonesia, an island renowned for its productive agricultural history and natural scenery. Strategically located on the westernmost end of the Lesser Sunda Islands, Bali was also known for its diverse landscapes, ranging from rice fields to volcanic highlands. Astronomically, Bali Island was located between 8°3’38”–8°50’56” South Latitude and 114°25’53”–115°42’39” East Longitude. Four districts were visited over a three-month period, selected using purposive sampling based on variations in waste management practices and agroecological zones. These four districts were chosen as primary observation sites due to their contrasting characteristics. Klungkung District was selected because of its high prevalence of rice straw burning and intensive rice cultivation practices. Gianyar District represented an area with significant challenges in compost adoption despite its large potential for rice straw waste. Tabanan and Buleleng Districts were chosen to represent the dynamics of the transition to organic farming and the challenges related to government policy support.

2.2. Writing method.

This study used a descriptive qualitative approach. This method was chosen to better understand how Bali managed agricultural waste and progressed toward organic farming. Kim et al. pointed out that this approach allowed researchers to apply various theories, sampling methods, and data collection techniques, thereby enabling the gathering of rich and detailed information. The findings were presented in simple, accessible language to ensure clarity and ease of understanding [18]. The analysis in this paper was based on a critical review of the literature and policy analysis. This approach aimed to develop a balanced understanding of the opportunities and challenges associated with agricultural waste management and organic farming. Berressem explained that a critical literature review enhanced the construction of research questions, broadened conceptual understanding, and provided foundational references for making comparisons and assessing the applicability of research within theoretical, policy, or practice settings. A systematic review involved comprehensive searching, cautious synthesis of results, and analytical appraisal of the degree, nature, and quality of evidence related to the targeted research questions [20].

2.3. Data collection.

Data collection for this research was carried out using several methods. First, a literature review was conducted to examine existing work on agricultural waste management and organic farming. A wide range of articles, journals, and reports was reviewed, including scientific studies, government documents, and policy papers related to agriculture in Bali and comparable regions. Field observations were also conducted at various farms in Bali to assess actual waste-handling practices. An Observation Checklist was used, which included indicators such as the presence of straw-burning residue, compost piles, biogas facilities, and the physical condition of the land. These observations were intended to verify discrepancies between field practices and sustainability claims, and to provide contextual understanding of the farming environment and the effects of existing waste management methods. In-depth interviews were conducted with 10 informants using source triangulation, focusing on technical barriers such as facilities and knowledge, financial limitations, and perceptions of government policies.

2.4. Data analysis.

The information gathered from the literature review and field observations was analyzed using a thematic analysis approach. The analysis unfolded in several stages. First, the collected data were coded to identify the major themes that emerged. Following the coding process, the themes were organized and categorized based on their similarity and relevance, with particular attention to issues related to waste management practices, successful approaches, and opportunities for transitioning to organic farming. Finally, the data were interpreted to develop a deeper understanding of the phenomenon under study. The results of the thematic analysis were cross-checked with existing literature to identify knowledge gaps and to formulate practical recommendations.

2.5. Data validation.

To ensure that the data remained valid and credible, data triangulation procedures were applied in this study. This involved comparing information obtained from various sources, including literature and observational findings.

3. Results and Discussion

3.1. Results.

3.1.1. Analysis of agricultural waste in bali: types and volume.

Agricultural wastes in Bali were a critical problem affecting agricultural productivity and environmental sustainability. One of the largest sources of agricultural waste was rice straw, as rice production generated up to 10 tons of straw per hectare at harvest. Farmers continued to burn straw despite its contribution to air pollution and soil nutrient depletion. Horticultural crop waste, including residues from vegetables and fruits, was also considerable. These residues were often burned or discarded, even though they could have been used as manure or animal feed. Waste from animal husbandry, particularly pigs and cattle, was similarly underutilized. Although manure served as a valuable source of organic fertilizer, much of it was wasted due to poor management. Burning agricultural waste, especially rice straw, resulted in the emission of greenhouse gases and harmful particulate matter, which were detrimental to environmental and human health. Waste burning caused the loss of organic matter in the soil, which was essential for maintaining soil fertility. Furthermore, unmanaged agricultural waste had the potential to pollute water bodies when washed into waterways without proper treatment.

Agricultural residues such as straw and horticultural waste could have been composted, producing a material that improved soil fertility while reducing the volume of waste needing disposal. In addition, agricultural waste could have been used as livestock feed, reducing wastage and providing farmers with a cost-effective feed source. Animal waste had the potential to be converted into biogas, which served as a renewable and cleaner energy source capable of reducing dependence on fossil fuels. The composition of agricultural wastes in Bali showed major challenges in waste management but also significant potential for improving agricultural sustainability. With efficient waste utilization, Bali could have reduced negative environmental impacts while enhancing agricultural productivity. Achieving this goal required the development of training programs and strong coordination among farmers, government agencies, and academic institutions.

3.1.2. Agricultural waste management practices in Bali.

Farmers in Bali managed their agricultural waste in various ways, largely depending on local knowledge, available resources, and customary practices. Most farmers continued to burn crop residues particularly rice straw, because they perceived it as a practical method for preparing land for the next planting cycle. However, as illustrated in Figure 1, this practice had significant environmental consequences. Some farmers began adopting composting methods to process vegetable waste and rice straw, but adoption remained low due to limited familiarity and inadequate facilities. Animal manure was often converted into organic fertilizer, yet its utilization remained insufficient, as many farmers did not fully apply it to their fields.

Figure 1. Farmers burn rice straw to speed up land processing and get ready for the next planting season.

Most farmers were not well-informed about sustainable waste management practices such as composting or biogas production. As a result, they relied on traditional, less environmentally friendly waste-handling methods. Farmers also lacked the tools and technologies necessary for implementing improved waste management practices. Financial constraints further hindered investment in modern equipment and facilities, as summarized in Figure 2. Farmers who had followed traditional practices for many years were often hesitant to adopt new waste management approaches. Doubts about the long-term benefits of alternative methods discouraged change. In addition, fluctuations in agricultural product prices and rising input costs discouraged farmers from allocating resources toward improved waste management systems. These factors collectively contributed to the continued neglect of more sustainable practices.

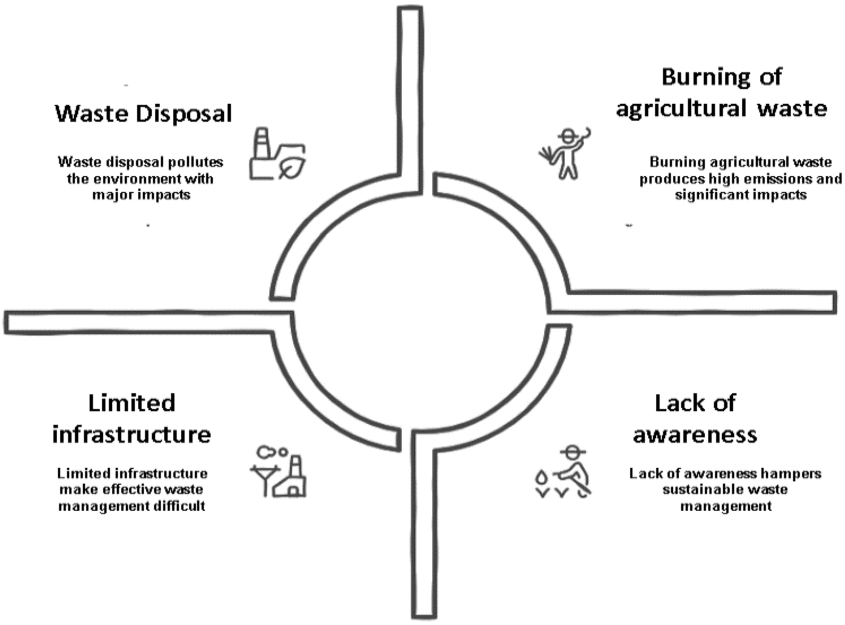

Figure 2. Challenges of agricultural waste management in Bali.

3.1.3. Agricultural waste management model in Bali.

Agricultural waste management practices in Bali were, at best, traditional and had hardly changed, meaning they were still closely linked to long-standing cultural customs and not much different from habits passed down from ancestors. These established methods were deeply familiar to most farmers and were preferred mainly because of their cost-effectiveness, even though they had serious environmental drawbacks. The continuation of these practices was largely driven by cultural norms and, to a great extent, by farmers' tendency to follow methods that had been proven reliable over generations.

Furthermore, another significant reason was the farmers' limited awareness of modern agricultural techniques, such as composting or biogas production, which was the main reason why sustainable agricultural waste management and its implementation remained major issues in the sector. This problem was further aggravated by insufficient access to resources, technology, and training opportunities, especially among small-scale farmers who often lacked the financial or logistical capacity to adopt new methods. As a result, Balinese agriculture continued to remain traditional in nature. Figure 3 shows the strengths, weaknesses, opportunities, and threats (SWOT) analysis of agricultural waste management in Bali.

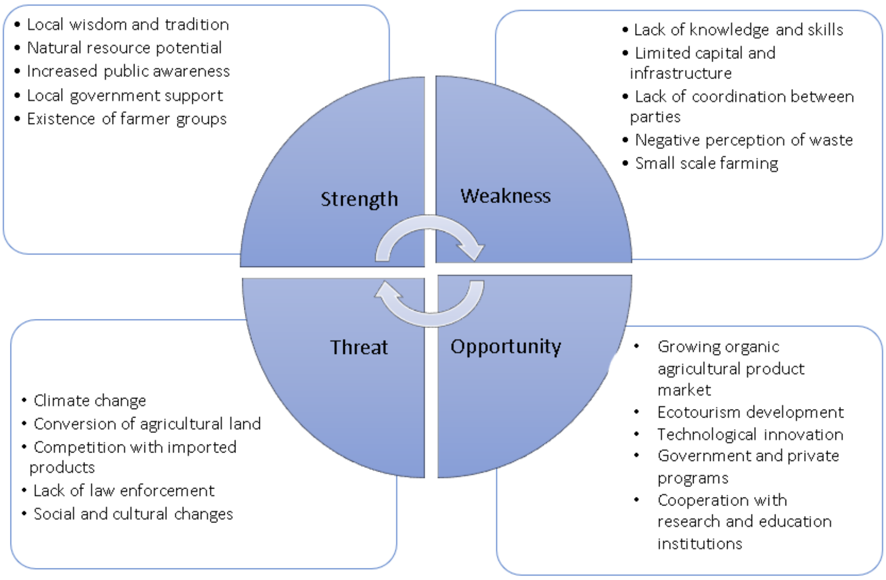

Figure 3. SWOT analysis of agricultural waste management in Bali.

Resistance to change also played a major role as a key obstacle. The lack of clarity regarding the impact of new methods made farmers cautious and reluctant to abandon familiar practices. Understandably, they perceived high risks and potential losses when considering untested approaches. In addition, limited policy support from the government further reinforced traditional models. Policies that did not promote or clearly outline sustainable agricultural practices caused farmers to feel there were no incentives or benefits in adopting new methods. However, despite these barriers, the challenges could also be transformed into opportunities for implementing the Sustainable Organic Loop Model for agricultural waste management in Bali. One promising approach was the development of educational and training programs. Increasing farmers' knowledge of green practices through these programs would make them more willing to adopt changes. Government involvement was also crucial; financial assistance for farmers who adopted green technologies and the provision of training facilities could motivate a more sustainable agricultural workforce.

3.1.4. Transitioning to organic agriculture: opportunities and challenges.

The Integrated Farming System program was a leading initiative in Bali that combined agricultural, livestock, and fisheries components into a single system. This initiative aimed to enhance productivity and sustainability by adopting a closed-loop natural cycle, in which the waste from one component served as input for another. Figure 4 illustrates the four main targets of integrated farming systems in Bali.

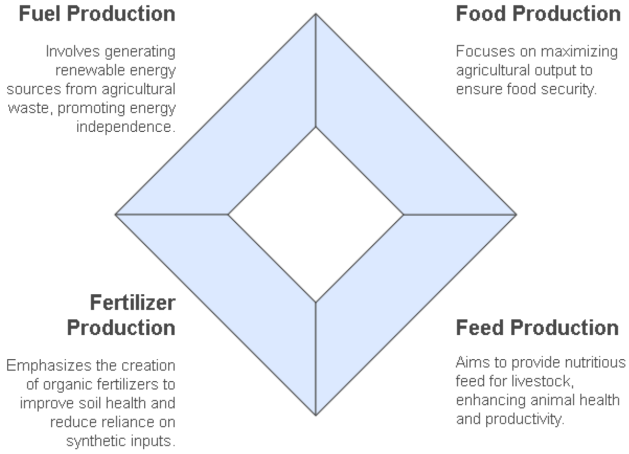

Figure 4. Four main targets of integrated farming systems in Bali.

For example, livestock waste was used as fertilizer for crops, while crop residues could be used as animal feed. The Department of Agriculture, with support from non-governmental organizations, established several training programs to empower farmers. These programs aimed to improve farmers' understanding of organic farming techniques, waste management, and the application of organic fertilizers. Farmers were trained to convert agricultural waste into nutrient-rich compost and to manage pests using natural pesticides. There was also initial collaboration with universities and research institutions to support the development of more efficient organic farming techniques. New plant varieties and improved waste management strategies provided farmers with better tools for implementing sustainable agricultural practices. Figure 5 presents the stakeholder challenges encountered in collaborating on the implementation of integrated farming systems in Bali.

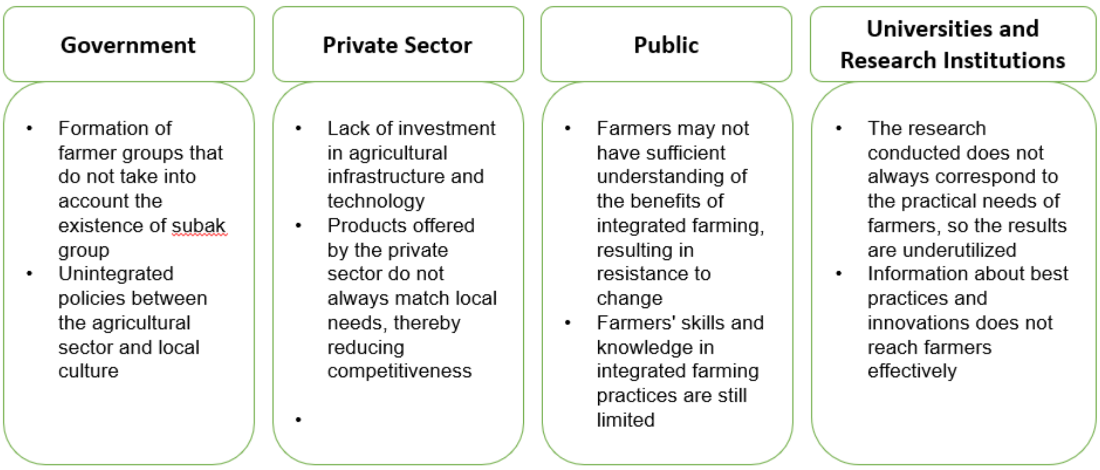

Figure 5. Stakeholder challenges in collaboration in implementing integrated farming systems in Bali.

Despite its strong potential to improve agricultural sustainability and productivity, the Integrated Farming System program still faced various challenges that hindered its implementation. Many participating farmers lacked sufficient knowledge of integrated farming principles. The training provided was often not comprehensive or consistent, making it difficult for farmers to apply what they had learned in practice.

3.2. Discussion

The Bali agricultural residues were broadly classified as rice plant residues, horticultural waste, and animal waste. Each category had unique characteristics and required specific treatment, yet all posed environmental concerns if not managed properly. Patil (2020) stated that the growth of agricultural production, which led to increases in animal waste, plant residues, and agro-industrial by-products, was inevitable. In the future, the expansion of agricultural infrastructure in less developed nations was expected to cause a substantial rise in global waste residues.

Agricultural waste, or agro-waste, remained a major component of the global waste management problem, as organic waste accounted for nearly 80% of agricultural solid waste [21]. Research on agricultural waste had progressed significantly, with new technologies and policies shifting its role toward sustainable development. These advancements not only improved resource efficiency but also helped mitigate environmental impacts [22]. Transforming agricultural waste into valuable resources such as biostimulants, biofertilizers, and biopolymers minimized environmental harm while supporting the development of a sustainable circular economy [23]. Organic recycling of farm waste improved soil fertility, increased crop productivity, and reduced greenhouse gas emissions, while also contributing to economic gains and rural livelihood opportunities [24]. Agricultural residues could additionally be converted into bioproducts and bioenergy, although challenges remained, including complex value chains, the need for technological innovation, and the necessity for cross-sector collaboration [25].

In 2023, Bali's rice farming covered approximately 108,514 hectares and produced 673,581 tons of dry milled rice, equivalent to around 379,870 tons of rice for human consumption [26]. One harvest generated an average of 10.21 tons of rice straw per hectare [27]. A study in Klungkung Regency reported that about 30.34% of farmers chose to burn rice straw after harvest, often based on the type of intercrop planted afterward [28]. However, retaining rice straw in the field increased overall grain yields by approximately 4.3% compared to leaving it off-field. The effects of straw return on yields and grain quality varied depending on plant variety, amount of straw returned, and method of incorporation [29]. Meanwhile, the use of agricultural waste from food crops as animal feed remained extremely low, primarily due to farmers' limited knowledge and insufficient feed-processing technologies [30].

Rice straw had been shown to be an excellent growth substrate for oyster mushrooms, producing higher yield and biological efficiency compared with corn stubble [31, 32]. Straw mushrooms also performed best when cultivated on rice straw, with faster fruiting body emergence compared to other agricultural wastes [33]. Furthermore, using rice straw as mulch or compost enhanced rice yield by increasing microbial diversity and improving grain quality; replacing just 10% of chemical fertilizer with rice straw compost significantly improved yield and quality [34]. Rice straw also had the potential to be converted into high-carbon and high-protein biofertilizers when mixed with other farm waste materials such as rice bran and fruit waste [5].

Bali was rich in local fruit varieties that required preservation and support for long-term sustainability. Through intervention programs and multi-stakeholder collaboration, these local fruits could be conserved and developed sustainably [35]. Fresh vegetables and fruits constituted nearly half of domestic food waste, which included unavoidable waste (approximately 21.1 kg/person/year) and avoidable waste (approximately 14.2 kg/person/year), with amounts varying across countries [36]. Vegetable and fruit waste contained valuable bioactive compounds that could be extracted for various industrial applications supporting sustainable development [37]. By utilizing this waste to extract bioactive molecules, industries could produce nutraceuticals, functional foods, and food additives while reducing environmental impacts [38].

The livestock sector in Bali, particularly cattle and pigs, generated substantial amounts of organic waste, mainly in the form of manure. Traditionally, livestock waste had been used only to a limited extent as organic fertilizer. However, it held significant potential for biogas production as a renewable energy source [39]. Bali's livestock manure had the potential to produce approximately 246,130.81 m^3 of biogas, or around 1,156,814.81 kWh per day, based on an average animal population of 19,183,779 head [40]. Proper livestock waste management enabled farmers to enhance profitability, reduce fecal contamination, and improve soil nutrient content [41].

Effective agricultural waste management was essential to prevent environmental degradation. Recycling agricultural resources allowed waste materials to be repurposed into useful products, reducing overall waste generation and decreasing the demand for new resources [15]. Agricultural waste included both utilizable and non-utilizable materials; converting them into usable products reduced pollution and supported environmental sustainability [42]. Moreover, recycling organic agricultural waste lowered greenhouse gas emissions and contributed to climate change mitigation [43].

Recycling agricultural organic waste was an effective strategy to enhance soil fertility, improve crop productivity, and reduce greenhouse gas emissions. It also created economic opportunities and employment in rural areas [24]. Through circular economy-based waste management, environmental quality could be improved, emissions reduced, and new investment and employment opportunities created, although logistical challenges and the lack of technical standards still needed to be addressed [44]. With efficient waste management and smart agricultural practices, soil health could be maintained while minimizing nutrient loss [45].

Agricultural waste management in Bali played a critical role in supporting the transition toward organic agriculture and sustainable farming industries. Conversion practices such as composting, liquid organic fertilizers, bokashi, and crop–livestock integration offered effective pathways to reduce waste. According to Parvaze and Kumar [45], evaluating the nutrient content of waste was essential for effective management. They noted that sustainable agricultural practices depended on minimizing storage losses and applying waste at the appropriate time to maintain soil quality. Reusing agricultural waste in organic farming reduced greenhouse gas emissions and improved agronomic performance [46].

Burning crop residues, particularly rice straw, remained a dominant practice among farmers in Bali. Farmers burned rice straw because it was perceived as simple, traditional, and convenient [27]. Many believed that burning rice straw improved soil fertility and reduced pollution because it was typically burned within a week of harvest [47]. Burning was widely seen as a fast, low-cost, and efficient method to prepare land for the next planting cycle [48].

A study in Klungkung Regency documented that burning rice straw during intensive rice cultivation led to the loss of between 5,887,086 and 7,888.7 tons of organic fertilizer. A major contributing factor was farmers' limited knowledge of composting techniques [27]. Rice straw burning also released substantial particulate matter and air pollutants, with consequences for local and global environments [49]. Nonetheless, agricultural residues still held significant potential to be reused or recycled to reduce emissions and combat climate change [43].

Composting offered a practical and low-cost method of managing agricultural organic waste while improving soil fertility and reducing environmental impacts [50]. However, farmers in Subak Telun Ayah, Gianyar, continued to burn rice straw due to limited knowledge of composting and skepticism toward compost benefits [51]. In general, farmers avoided composting because they lacked understanding of the process [52]. While challenges existed in compost production and marketing, opportunities for integrating compost into agricultural practices were substantial [53].

Bali generated large amounts of agricultural residues, including rice straw and coffee husks, which could be recycled as animal feed [54]. Literature indicated that transforming agricultural waste into sustainable livestock feed was a promising waste-management approach [55]. Integrating by-products, maximizing forage, and adopting crop–livestock systems enhanced land-use efficiency and strengthened agri-food system sustainability [56]. Farmer training was essential for maximizing the use of agricultural waste as animal feed. Such training not only met farmers' own needs but also opened economic opportunities for selling feed to other regions [57]. Training programs in Bali significantly improved farmers' understanding of good feeding practices [54].

One of the major challenges in using agricultural waste in Bali was farmers' reliance on traditional, non-scientific methods. Straw burning persisted due to perceptions of convenience. In Gianyar's Subak Telun Ayah, farmers burned residues due to a lack of knowledge on soil-enriching benefits of straw. Many also distrusted compost and preferred inorganic fertilizers [51]. Around 30.34% of farmers in Klungkung burned straw because it was considered the most convenient recycling method [27]. Burning also depended on the type of post-rice crops, such as peanuts or corn, with farmers believing that straw ash improved yields [28]. Farmers also struggled with waste utilization because the process was costly and required proper equipment and composting areas. Farmers in Asah Duren Village noted they had never produced compost because they lacked knowledge and facilities [52]. Moreover, labor shortages, limited land, and time constraints hindered effective waste management [58, 59].

The Sustainable Organic Loop model was an ideal choice for agricultural waste management and organic farming development in Bali. The model was integrated, combining agricultural waste management with organic farming practices. Its goal was to create a sustainable farming system that optimized waste while enhancing productivity. Although comparable to the closed-loop model of the circular economy, it emphasized creating a sustainable organic cycle. As emphasized by Gholipour et al. (2024), a sustainable closed supply chain aimed to decrease costs, lower risks, and maximize returns by converting organic waste into productive products such as ethanol or compost. Essentially, waste or by-products from one process became inputs for another, minimizing waste and maximizing resource efficiency [61]. Future studies were expected to explore how this model could be extended to other sustainable business sectors, such as zero-carbon technology or short supply chains [62]. The rationale behind this model lay in the significance of closed-loop systems, which minimized waste, enhanced soil fertility, and promoted biodiversity. The model served as a blueprint for farmers and other stakeholders to adopt sustainable practices that supported healthier ecosystems. For instance, in Brazil, closed-loop systems effectively treated organic waste, produced fertilizer, and generated additional revenue for farms, ultimately enhancing resilience and financial security for family farmers [63].

Closed-loop farming systems were reported to save approximately 40% of irrigation water and 35–54% of nutrients on a daily basis. This not only helped control eutrophication but also addressed global warming [64]. These systems reduced dependence on external inputs, minimized environmental degradation, and transformed waste into productive bioenergy and biofertilizers without diminishing soil fertility or natural resource quality [65]. Transitioning to these systems required substantial capital for technology, equipment, and training. For small-scale operations, these costs posed significant barriers, limiting adoption [66]. The closed-loop design generated organic nutrient sources that played a central role in ecological soil nutrient management and thus represented a valuable asset for achieving sustainable development goals [67]. Closing the resource loop involved composting plant residues and organic matter. Through composting, carbon dioxide and plant nutrients could be recycled and reutilized as farm inputs, while organic waste was efficiently valorized [68]. In addition, closed-loop farm systems supported irrigation scheduling and offered benefits such as convenience, profitability, and environmental sustainability [69].

These systems also had the potential to sequester carbon, enhance soil quality, and yield bioenergy, generating additional income [70]. Sustainable agriculture was closely linked with soil health, as the activity and diversity of soil microorganisms played a critical role in maintaining soil vitality. Agricultural sustainability referred to crop production systems' ability to provide food without negatively impacting the environment [71]. In electrical conductivity-based closed-loop systems, variations in plant nutrient absorption could be monitored; however, conventional nutrient replenishment systems did not always follow this regularity [72].

Fostering cooperation among governments, businesses, schools, and researchers was crucial for adopting circular economy strategies, particularly to minimize food loss and greenhouse gas emissions [73]. Circular economy practices in agriculture—including biomass production, waste minimization, and pollution control—helped mitigate climate change, conserve biodiversity, and enhance economic growth and sustainability [74]. Effective solid waste management promoted sustainability through reduction, reuse, and recycling, influenced by geographic and economic contexts [75].

Major challenges of closed-cycle agricultural waste management systems included evaluating environmental and economic impacts, improving anaerobic digestion, and ensuring collaboration between agricultural and industrial value chains [25]. Internally, challenges included recovering carbon dioxide and plant nutrients, bridging operational gaps, and introducing new technology [68]. Globally, agroecosystem waste management was hindered by limited treatment technologies, environmental conservation needs, and food safety concerns [76]. Bali Province also promoted organic farming via the Sustainable Organic Loop model, emphasizing government efforts through the Simantri program, which aimed at integrated farming. However, program implementation fell short due to insufficient assessment and assistance. Sahri (2023) reported challenges including ineffective livestock manure processing, conflicting institutional interests, and disengaged farmer groups. Additionally, limited farmer knowledge, lack of technological adoption capacity, and inadequate funding exacerbated the difficulties [78]. Generally, combining sustainable agriculture with traditional practices was hindered by limited technology access and weak policy support [79].

Minimizing waste through recycling and reuse of materials was a key element of the Sustainable Organic Loop approach. Crop residues could be converted into compost, enhancing soil fertility and creating a sustainable cycle where waste became productive input [80]. The model emphasized sustainable organic farming methods that improved ecosystem health and optimized resource use. Organic farming reduced environmental damage by avoiding synthetic chemicals, thereby maintaining soil, water, and biodiversity—essential components for long-term sustainability [81]. Organic agriculture also reduced greenhouse gas emissions and, when combined with conventional farming, could enhance global agricultural productivity [82]. The Sustainable Organic Loop Model primarily functioned as a nutrient recycling system rather than a simple waste management framework. It reduced reliance on external inputs and increased natural resource efficiency [83]. Its implementation required cross-sector collaboration, government support via regulations and incentives, and academic contributions through research, development, and knowledge transfer (Figure 6) [84, 85].

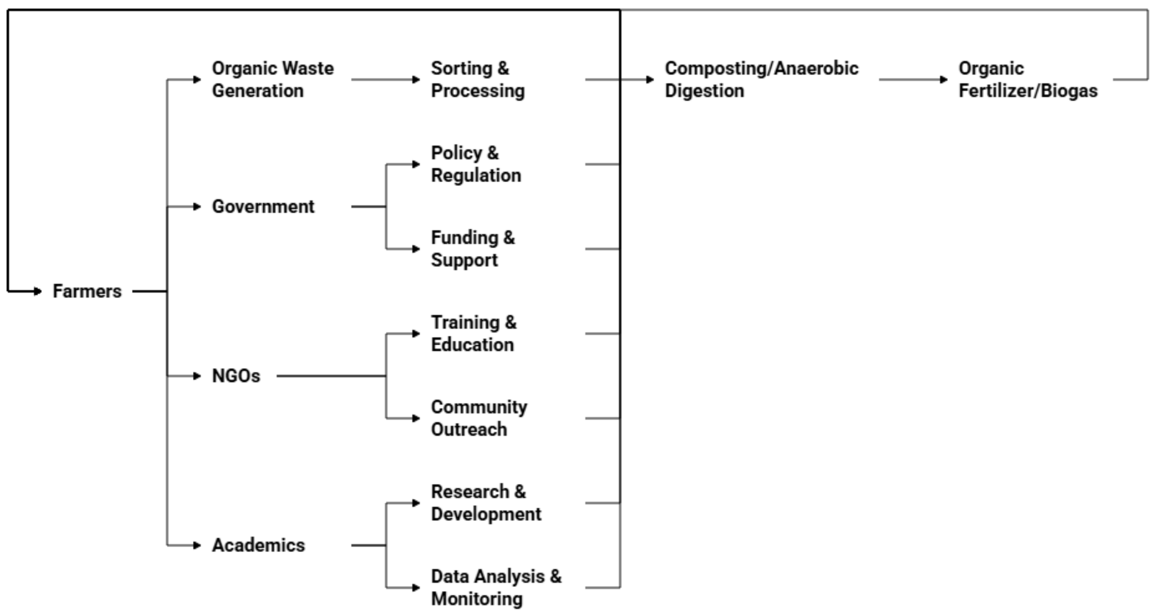

Figure 6. Collaboration diagram in the 'sustainable organic loop model' which illustrates the relationship between farmers, government, non-governmental organizations (NGOs), and academics.

Despite the growing popularity of organic farming in Bali, transitioning to sustainable recycled farming required technical assistance and greater familiarity with organic practices. Demystifying organic farming and clarifying national standards for consumers and farmers were necessary [86]. Integrated Organic Farming Systems provided a solution by harmonizing nature conservation with food production, minimizing chemical use, and promoting recycling and reuse of farm wastes [61]. Organic farming in Bali had expanded since 2006 through collaborations with the government, private sector, and certification bodies. The system showed strong sustainability potential, complying with established standards [87]. Organic farming could be applied in nearly all regencies except Klungkung and Denpasar, where certification based on national standards was not yet obtained, limiting expansion [88].

While organic farming conversion offered higher productivity and sustainability, challenges persisted, including limited organic fertilizer, insufficient irrigation, and weak market support [87]. Constraints such as reduced yields and nutrient management difficulties also affected small-scale farmers [89]. Other obstacles included limited technical guidance, funding for certification, and consumer willingness to pay premiums [87, 86]. For example, resistance to organic rice farming in Buleleng Regency resulted from unsupportive policies, market difficulties, internal issues, and inefficiencies in the Subak system [7]. Organic farm product marketing faced challenges, including expensive certification, high product prices, reduced production, and low consumer awareness [90–92]. Promoting sustainable and profitable organic farming required product diversification, environmentally friendly practices, and online marketing [93]. Effective management and marketing were essential for long-term viability and value addition [94].

The implementation of integrated farming for organic agriculture had been carried out internationally, adapting to local conditions. In India, the Integrated Organic Farming System (IOFS) increased crop yields by 20–50% and improved farmer income and nutrient utilization through organic waste recycling [61, 95]. In Europe, countries such as Italy, France, and Germany led organic farming development, supported by government policies and incentives, although adoption rates and challenges varied [96, 97]. Studies in Hungary showed that agroecological integration enhanced resilience and productivity, despite economic sustainability challenges [98]. In Latin America, local actor involvement in Costa Rica was critical to policy success [99]. Integrated farming systems toward organic farming provided multiple benefits: improved farmer livelihood security, cost efficiency, product diversification, higher productivity and income, enhanced soil quality, increased biodiversity, and reduced reliance on chemical inputs, supporting environmental and human health [95, 100–102]. Weaknesses included limited organic fertilizer availability, weed management challenges, high technical requirements, and restricted access to training and technology [61]. High certification costs and suboptimal marketing further hindered small farmers [101]. Figure 7 illustrates the role of each stakeholder in supporting organic farming collaboration.

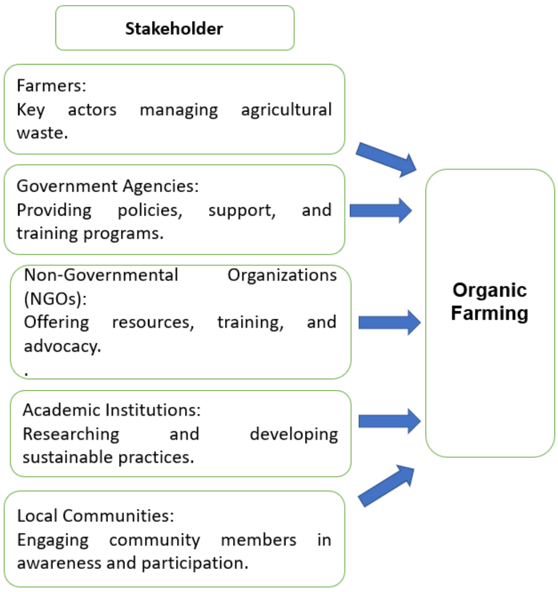

Figure 7. The role of each stakeholder in building collaboration towards organic farming.

The success of the integrated model depended on active engagement from all stakeholders, farmers, government, NGOs, and academics, each complementing the others. Farmers required technical support, market access, and incentives, while the government provided policy, regulation, and infrastructure facilitation [103]. Collaboration improved training effectiveness, strengthened community practices, and encouraged pro-environmental behavior among farmers [104]. Multi-party involvement enhanced transparency, responsiveness, and sustainability, amplifying the positive impacts of organic farming [105].

Implementing integrated organic farming had significant implications for the Bali provincial government. Strengthening policy, infrastructure, and technical assistance ensured program sustainability, including Simantri, which improved organic fertilizer production, farmer income, and local economic resilience. Developing an integrated and accessible organic database allowed targeted decision-making. Additionally, training, counseling, and field demonstrations based on local wisdom, such as Tri Hita Karana, increased the adoption of environmentally friendly technologies and stakeholder synergy.

4. Conclusions

There was a critical gap in agricultural waste management between organic farming policies and the reality on the ground in Bali. Agricultural waste, such as straw and horticultural residues, had the potential to be processed into compost or animal feed, but many farmers lacked understanding of how to manage it effectively. The Sustainable Organic Loop Model offered a novel approach to waste management, in contrast to the fragmented strategies previously applied in organic farming. Unlike earlier studies, which largely focused on technical aspects of organic yields or single-policy analyses, this study integrated agroecological zoning with the Quadruple Helix stakeholder framework. The findings confirmed that the persistence of rice straw burning (30.34% in Klungkung) was not merely a technical failure but reflected a lack of systemic integration between the Integrated Farming System program and the local Subak adaptive mechanisms. The Integrated Farming System program in Bali provided opportunities to use waste from one agricultural component as input for another, yet it still faced challenges related to knowledge gaps and limited access to technology. Overcoming these barriers required close collaboration among all stakeholders. By establishing a robust collaborative strategy including provision of resources, training, and policy support,Bali could transition to more environmentally sustainable organic farming, thereby enhancing farmer productivity and well-being.

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Author Contribution

I Nengah Muliarta: Conceptualized the research idea for this review and formulated the research questions. Conducted the descriptive qualitative research methodology, including data collection and curation (literature review). Conducted the formal analysis and visualization of the Sustainable Organic Circle Model collaboration framework. Prepared the original draft of the manuscript. Ni Ketut Sri Rahayu: Provided initial conceptualization of the study. Supervised and validated the theoretical framework and stakeholder collaboration model. Contributed to substantive writing, review, and editing of the final manuscript. Provided resources and project administration.

Competing Interest

The authors declare no relevant conflicts of interest related to this research. All data and results presented in this article are outcomes of independent research and were not influenced by personal, commercial, or professional interests that could compromise the integrity or objectivity of the research. The authors did not receive financial support, donations, or incentives from third parties that could influence the results or interpretation of this study.

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