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Utilizing Dairy Waste Processing for Organic Agricultural Production: A Sustainable Approach to Producing Organic Goods

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Abstract: Resources are limited. Thus, farmers worldwide are trying to use their waste to best extract value that can promote environmentally friendly farming. Recycling dairy waste for organic cultivation seems to be one of the alternative approaches to pursuing environmentally friendly agriculture. This study investigates whether or not dairy waste treatment could improve organic crop production and promote a circular economy. This endeavor examines the credible benefits, obstacles, and consequences of incorporating dairy waste into organic farming practices. Using System Dynamics and case study approaches, including field trials, agricultural evaluation of data, and discussions with stakeholders, the research strategy advocates investigating how dairy waste-derived fertilizers influence soil fertility, crop productivity, and product quality. Interaction with stakeholders helps evaluate the viewpoints of growers, dairy producers, legislators, and consumers regarding adopting dairy waste treatment for organic agricultural growth. This study demonstrates how dairy waste processing can serve as a significant source of biofertilizer for organic farming. The beneficial impact of organic fertilizer derived from farm waste improves the nutritional value of organic crops, crop yield, and soil health. The crop production information collected in the study demonstrates that dairy waste-derived fertilizers are nutrient-dense and could substitute for manufactured/chemical fertilizers economically and environmentally. This study emphasizes the need for creative ideas to improve agricultural sustainability. The present study advances the understanding of sustainable agriculture and offers practical advice to those looking to use greener methods of operation.

Keywords: dairy; waste; sustainability; organic; agriculture; Bangladesh

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1. Introduction

In recent years, sustainability has become increasingly crucial in various sectors, including dairy farming. An increasing demand for sustainable dairy farming techniques facilitates population growth and environmental challenges [1]. Also, processing dairy waste for use in environmentally friendly organic fertilizer and crop production could enhance soil fertility and crop productivity while resolving waste management problems [2]. This paper examines the current state of the relevant research and the need for upgrades, as farms generate plenty of manure, whey, and wastewater from dairy farming activities. Such wastes lead to the contamination of the water supply, emissions of greenhouse gases, and odor [3]. Waste treatment technologies have transformed dairy waste processing into something more environmentally friendly.

Organic agriculture could gain more benefits from dairy waste transformation [4,5]. Adequately treated waste from dairy farming could provide nutrients, minerals, and beneficial microorganisms, boosting soil condition and developing diverse, healthy plants [6]. For instance, composting dung from cows alongside other naturally occurring substances produces nutrient-rich compost that develops soil, absorbs water, and fosters microorganisms [7]. The anaerobic fermentation of cattle waste generates biogas for power, and high nutrient decomposition improves soil quality. Integrating dairy waste management with organic farming enhances the sustainability of agriculture. Organic farming also emphasizes biodiversity and ecological harmony, making cow manure an appropriate fertilizer and amendment to the soil.

The potential of organic agriculture is the prospect of organic farming techniques to enhance ecosystems, restore the condition of the soil, and reduce adverse environmental effects through less usage of synthetic substances like fertilizers, pesticides, and herbicides. Organic farming promotes a healthy environment, fosters better quality crops, and fulfills customer demands for sustainably grown food products [8]. Improving waste disposal methods to be more effective and affordable is essential to improving the dairy process [9]. There are numerous methods to enhance composting and anaerobic digestion's productivity, consumption of energy, and impact on the environment [10]. Additionally, additional research is required to assess the long-term effects of dairy waste treatment on soil conditions, crop production, and the overall quality of the environment. Although investigations have demonstrated agronomic benefits associated with using waste from dairy production as a soil nutrient supplement, additional research will be required to evaluate its impact on agricultural productivity and reducing greenhouse gases.

Although improving process efficiency [11] offers long-term benefits, there is still a need for advancements in organic farming methods. Current investigations indicate that such an integrative approach is feasible and beneficial. Recycling dairy waste efficiently and collectively builds an efficient and sustainable food framework for future generations. Managing water resources and environmental protection constitute two domains where holistic and sustainable farming methods are becoming increasingly vital. Further studies need to connect dairy waste utilization with agroecology concepts, including crop rotation, grazing rotation, and agroforestry. Ecosystem-based farming techniques and dairy waste management could improve farm resilience, reduce adverse ecological repercussions, and promote the sustainability of food systems. Dairy waste treatment offers an opportunity to improve soil fertility and waste management in sustainable organic agriculture.

Objectives

1. Evaluate the current processing and transformation techniques used to convert dairy waste into biofertilizers and biogas to meet agricultural demands while improving organic ingredients.
2. Assess the consequences of fertilizers derived from dairy manure on soil fertility, the yield of crops, and the quality of the products of organic farming.
3. Evaluate the sustainability of and stakeholder perspectives on including dairy waste processing in organic farming techniques.

2. Literature Review

This section discusses organic farming sustainability, dairy waste processing, and Bangladesh's dairy farming operations, including production systems, cattle breed availability, feed habits based on available resources, cattle health care management, reproduction management, and market mechanisms. Such discussions and literature support an understanding of the real-life circumstances of dairy farming in Bangladesh and the challenges to be overcome in the coming days. Factors and trends driving organic demands, which strongly correlate with existing waste management systems, are also mentioned. Healthy waste management can provide organic substances like biofertilizers, which can be used on agricultural lands to raise healthy crops for customers.

2.1. Organic Farming and Sustainability

There is growing interest in using dairy waste in agricultural systems to improve the sustainability of organic farming. Research emphasizes the effectiveness of utilizing animal waste as an organic fertilizer, which reduces dependency on synthetic fertilizers, improves the foundation of the soil, and ensures productivity over the long term [12]. The cycling of nutrients fosters a circular economy in rural areas by promoting environmentally friendly farming methods and decreasing the operational difficulties of dairy waste management. The objective of minimizing the environmental impact of farming and enhancing or preserving productivity promotes sustainable farming [13]. Organic agriculture utilizes decomposition and organic pest control rather than artificial fertilizers and chemical pesticides. The new approach relies on dairy waste to increase soil microorganisms and retain water. Research shows that dairy waste-derived fertilizers made from organic matter can boost crop yields, prevent soil erosion, and increase crop resilience to climate change [14]. Organic farming and dairy waste recycling improve resource efficiency on farms and benefit the environment.

Sustainable agricultural development necessitates effectively utilizing renewable resources to maintain soil fertility and improve the ecological balance. Recent studies show that dairy waste may contribute to organic farming by improving sustainable agriculture ideas [4,8]. For example, dairy manure's capacity to sequester carbon assists in lowering greenhouse gas emissions and boosting soil health [15]. In addition, research indicates that applying organic fertilizers derived from dairy manure increases wildlife biodiversity by reducing chemical residues in the soil and water. This approach maintains sustainable agricultural production while supporting healthy ecosystems, which aligns with the principles of organic farming.

Dairy waste processing constitutes a sustainable technique for producing organic products that help farmers economically and environmentally. Farmers can reduce production costs and regain an advantage over premium organic marketplaces that require environmentally conscious products by reducing their dependence on chemical inputs. Moreover, using dairy waste improves local food systems, reduces environmental risks, and strengthens the capacity for resilience. The literature shows that recycling dairy waste is crucial to sustainable agriculture and supports the broader goals of organic farming. These include soil preservation, biological health, profitability, and providing the way to a more environmentally friendly agricultural future.

2.2. Bangladesh and Its Dairy Operations

The Bangladeshi livestock sector relies on dairy production for food security, rural livelihoods, and economic growth [16]. This study covers Bangladeshi dairy farming, including the production process, breed selection, feeding procedures, health management, value addition, and waste management.

2.2.1. Production Systems

Size, animal breed types, ownership, and milk processing categorize Bangladeshi dairy farms [17]. Dairy farming is primarily divided into small-scale (2–5 cows), medium-scale (6–9 cows), and large-scale farms (more than 10 cows) [18]. Most farms use traditional production systems and hold their animals as part of their household responsibilities. Apart from this, many commercial farms exist in Bangladesh and have herds of different sizes, from 20–100 cows. The authors interviewed case farm owners and farm managers to verify their observations that mid-size farmers rear between 100 and 200 cattle.The largest dairy holds over 1600 cattle of different ages, producing 7000 L of milk. According to the association spokesperson, small, medium, and large-scale farms can skim 2–4, 4–7, and 10–16 L per day of milk from a milking cow. Dairy cows in Australia usually yield an average of 28 L a day [19]. Bangladesh is well behind in such productions due to its breed, feeding quality, and healthcare management. Dairy farms with over a hundred cattle maintain modern feeding and breeding methods. Modern systems also include stall-feeding, 24-h veterinary care, integrated supply chain networks, value-addition facilities, and waste management plants. In contrast, traditional systems provide broad pasture with little control, as most farms are smallholders with fewer than five cows.

2.2.2. Cattle Breed

A cattle breed represents a collection of native cattle with distinct genetic and physiological features that were crossed for specific purposes, such as dairy milking, meat, or labor (cultivation). Breeds are developed to enhance attributes like resilience, speed of growth, and milk production to comply with diverse farming objectives. Climate, feed availability, and milk productivity affect Bangladeshi dairy breeds. The authors of this study struggled to find accurate information on breed availability; we found examples of existing dairy cattle breeds, including exotic breeds like the Holstein Frisian, which the government promotes through artificial insemination. In addition, the Jersey, Sahiwal, and Sindhi breeds are available along with native breeds like Red Chittagong, Pabna, North Bengal Grey, Munshiganj, and non-descriptive local cattle. Although 92% of the native cattle originated from the breeds mentioned above [20], their low rate of fertility and cross-breeding issues lead to poor milk production [21]. Various breeds are combined whenever cows are cross-bred to enhance qualities like disease resistance and milk yields [22]. Native breeds like the Red Chittagong and Deshi are well-adapted to local environments but produce less milk than imported breeds like the Holstein-Friesian and Jersey. Differing regions have had varying success with cross-breeding projects to boost milk output and flexibility.

2.2.3. Feed Habits

Cattle feed plays a vital role in dairy farming. It emphasizes high-energy feed containing sufficient carbohydrates, protein, and essential minerals for optimal milk production. A blend of grain, hay, and green grass is frequently utilized in feed schedules to keep cows healthy and producing milk regularly. Most of the cattle are located in rural areas, and there are insufficient facilities to feed them scientifically. Observation reveals that cattle feeding is not the only issue. Many things, like cattle health, housing, nutrition, comfort, movement, and human-animal interaction are not maintained per standard procedures. Islam et al. (2020) assessed welfare in 70 small dairy farms and revealed a high incidence of body scratches, limited understanding of animal welfare, and low vaccination rates, highlighting the need for scientific housing and health management to enhance productivity and cow welfare [23]. In the actual scenario, dairy farmers feed according to feed availability, price, and dietary needs. Traditional feeding uses locally available fodder, crop remnants, kitchen trash, concentrates, and minerals. By contrast, contemporary dairy farms blend green feed, silage, concentrates, and mineral combinations to maximize milk output and animal health.

2.2.4. Manage Cattle Health

To maximize production and life expectancy, cattle need to be properly and efficiently handled, such as through periodic examinations, deworming, and vaccinations. Controlling diseases and the prompt treatment of health problems improve milk output rates, thereby improving dairy farming's overall success. Given the frequency of mastitis, foot-and-mouth disease, and internal parasites in Bangladesh, dairy production requires proper and scientific health management services. Traditional doctors, homeopathy, and herbal medicines are sometimes but not always adequate [24]. Modern dairy farms use vaccination, deworming, and cleanliness to reduce illness and increase herd health.

2.2.5. Reproduction Management

In the dairy industry, reproductive management involves managing genetics, bloodlines, and breeding cycles to ensure an increased quantity of milk and the healthy development of the herds [25]. Reproductive management is also crucial for dairy herd fertility and genetic advancement. Instead of natural mating and optical estrus detection, contemporary farms use artificial insemination (AI) and estrus synchronization to increase breeding efficiency and genetic purity. Many dairy farms struggle with poor conception rates, erratic estrus cycles, and limited AI services. Traditional farms still rely on bull insemination for reproduction. Often, farmers fail to get optimum results, which causes significant delays in getting timely pregnancies.

2.2.6. Market Mechanism

Bangladeshi dairy marketing tactics rely on farm size, geography, and market access. Local cooperatives, community collecting centers, or intermediaries sell milk from smallholder farmers to metropolitan markets [26]. Milk processing factories or cooperatives may connect larger farms to urban markets, giving them higher-value prospects. Often, farmers do not get the optimum price, discouraging them from extending their farm size due to possible negative profits.

The above-mentioned factors challenge the sustainability of dairy farming by complicating the selection of suitable cattle breeds and feeding practices that optimize milk production, support stable productivity through animal health care, and ensure a steady resource supply for dairy cattle. Consistent reproduction ensures significant waste collection from a dairy farm, which can be utilized to improve soil fertility and crop productivity in organic agricultural operations.

2.3. Challenges

According to case farm owners (Rahman, 2024), dairy farming businesses in Bangladesh face climate change, input shortages, infrastructural issues, and lack of adequate technical support. However, the increasing demand for milk and dairy products, government support for dairy development initiatives, and technical advances in breeding, feeding, and management offer growth and development prospects. The Bangladeshi dairy industry supports sustainable agriculture and nourishment for millions of underprivileged and rural people. The sector offers tremendous potential for growth despite poor efficiency, epidemics of diseases, and accessibility to market issues. Breed development, nutrition formulation, feeding techniques, governance of cattle health, underpricing, and access to markets may assist in achieving sustainable dairy farming goals.

2.4. Factors and Trends Driving Organic Demand

The demand for organic agricultural goods has expanded as consumers' knowledge of food safety, quality, and sustainability has improved [27]. Buyers gravitate toward organic food, since they have reservations about synthetic ingredients, genetically modified organisms, and residual pesticides in regular foods. Organic agriculture produces more nutritious and healthier crops than traditional farming, as it emphasizes soil health, biodiversity, and organic inputs. Popa et al. (2019) indicate that organic vegetables might have more significant quantities of vitamins, antioxidants, and minerals, consequently improving their nutritional value and general well-being [28].

Rising Sustainability Concerns

Consumers seek sustainable alternatives due to traditional agriculture's land deterioration, water pollution, and greenhouse gas emissions [29]. Organic agricultural methods, including crop rotation, composting, and biological pest management, are considered more eco-friendly. Due to the certification regulations and regulatory controls applied to organic agricultural goods, organic farming processes have gained public confidence and trust. Organic certification promotes animal welfare, biodiversity protection, and the restriction of synthetic pesticides, herbicides, and fertilizers.

The organic market has expanded due to the increased availability and accessibility of organic products in retail outlets, supermarkets, and online platforms. A broader selection and lower prices make organic products increasingly appealing to customers for health, environmental, and ethical reasons. Increasing consumer knowledge, health consciousness, environmental sustainability concerns, certification criteria, and market accessibility will increase the demand for organic agriculture products. The organic sector will grow and diversify as consumers prioritize health, sustainability, and ethics.

3. Materials and Methods

The present research examines dairy sustainability and integrating waste management and organic agriculture practices with qualitative and quantitative techniques. This study utilizes the System Dynamics method and draws on the Vensim 6.0b simulation application to enhance the existing model. Forrester (1995) developed the System Dynamics model for economic systems, and this study follows the same procedures to depict a process model to examine the utilization of dairy wastes. The methodology employs System Dynamics [30] and uses the simulation software Vensim to model the complex interactions [5,31] between dairy waste processing and organic agriculture. This allows for the simulation of feedback loops and policy impacts. This approach enables the analysis of variables like cattle health, feed, and market dynamics, optimizing waste utilization. To find sustainable outcomes, the model eventually incorporates biogas and biofertilizers as input variables across the surrounding agricultural lands. Using a multifaceted approach, like in-depth interviews with farm owners (Managing Director of the farm) and officials (two administrative employees for data collection, refinements, and validation), the study gathers and evaluates qualitative and quantitative data regarding the productivity, utilization of resources, and sustainable impacts of interactions between Later, the model was compared with existing and hypothetical data on the better utilization of waste resources; Initially, this study builds a conceptual model (Figure 1), followed by the development of a simulation model (Figure 2). Figures 3–6 compare the two different scenarios and demonstrate the results. This research labeled the two processes as 'current' and 'improved'. The graphical representations from the simulation model supported sustainable dairy operations and organic farming by promoting effective waste management. The research also involved unstructured conversations with the biggest milk producer, revealing operational issues associated with waste management and its environmental and technological implications. The research team conducted several rounds of informal conversations with dairy employees, workers, intermediaries, and other supply chain stakeholders to determine the real scenarios that would result if parameters were changed. For example, if waste collections were improved by ten percent, hopefully, this would be helpful for the farm. In another instance, if a farm uses chemical fertilizer on adjacent lands, what if they instead used their by-products like biofertilizers, what would the outcomes be? The farmers have been experimenting for a long time, and they have a clear idea of what they are talking about and what the outcomes would be. Such inputs helped the authors of this study to run the model with improved scenario perspectives and compare the results to determine the most efficient operations.

4. Results

Table 1 compares the dairy farming process with organic agriculture, highlighting key distinctions based on the farmers' opinions. There are discrepancies regarding the way both systems support environmentally friendly farming. The dairy fertilization process utilizes dung to supply organic nutrients to crops, while organic agriculture emphasizes manure's contribution to reviving soil fertility for harvesting efficiency. Dairy farming enhances the soil's composition and retains moisture using compost.

The comparison encompasses controlling pests, biodiversity, and the utilization of resources. The dairy industry employs insecticides to deal with pests, whereas organic agriculture uses IPM to limit the use of chemicals. Dairy operations utilize agroforestry and diversify livestock feed, while organic agriculture uses the rotation of crops and preservation of habitat to foster biodiversity. Another objective is to use resources sustainably, particularly in dairy farming, recycling nutrients via manure and organic agriculture and restricting the use of synthetic sources.

Both approaches promote the welfare of animals, competitiveness, and resilience in communities, both socially and economically. Organic agriculture blends livestock rearing with crop management for sustainability, while dairy farms adhere to pasture and humane treatment. Both bring in money from organic accreditation and premium markets. Dairy farming supports regional food systems and small-scale farmers, protecting food security. On the other hand, organic agriculture promotes economic resilience through community involvement. Table 2 demonstrates how both systems are integrated to achieve sustainable and profitable agriculture. In-depth interviews with the farm owner and top executives were conducted to develop Table 2, which explores approaches for transforming waste into organic by-products. Interviewees highlighted the cost-saving benefits and potential for achieving organic goals.

Table 1. Relationship between dairy farming process and organic agriculture.

Particular	Dairy Farming Process	Relationship to Organic Agriculture
Nutrient Cycling	Manure provides organic nutrients for crops.	Manure enriches soil fertility, promoting sustainable crop growth and reducing reliance on synthetic fertilizers.
Soil Health Improvement	Organic matter enhances soil structure and moisture retention.	Improves soil water-holding capacity and microbial activity, leading to healthier crops and better yields.
Integrated Pest Management (IPM)	Uses biological controls to manage pests.	Dairy farms reduce pest control, supporting organic IPM strategies to decrease pesticide use.
Sustainable Resource Utilization	Recycles nutrients efficiently through manure application.	Lowers environmental footprint by reducing synthetic inputs and promotes eco-friendly agriculture.
Biodiversity Conservation	Provides diverse fodder and adopts agroforestry.	Increases biodiversity, creating resilient ecosystems that benefit organic crop production.
Animal Welfare	Prioritizes animal access to pasture and humane treatment.	Improves animal health, ensuring higher quality organic animal products through grazing lands and corn stover or paddy straw.
Regenerative Agriculture	Uses manure for soil fertility and carbon sequestration.	Supports organic practices in enhancing ecosystem health and mitigating climate change.
Market Access	Organic practices offer access to premium dairy markets.	Increases profitability by accessing premium organic markets for crops and livestock.
Community Resilience	Supports local food systems and small farmers.	Strengthens local economies and ensures sustainable food systems through collaboration.
Additional Production Cycles	Aligns milk production with crop harvests for stability.	Synchronizes crop and livestock cycles, improving productivity and resource use efficiency.
Feed Source Integration	Uses crop residues like straw as fodder.	Reduces waste by recycling crop residues, lowering feed costs, and benefiting organic pest control.

Table 2. Organic practices, benefits, and cost savings based on dairy waste.

Dairy Waste	Organic Practice	Benefit	Cost Savings	Organic Achievement
Cow dung	Organic fertilizer for crops	All crops, particularly vegetables, fruits, and grains	Reduced fertilizer purchase costs	Improved soil fertility and productivity, reduced chemical inputs
Dairy manure	Biogas	Biogas slurry to crops	Reduce energy costs	Reduce fossil fuel usage
Dairy by-products (e.g., skim milk)	Soil amendment and composting material	Vegetables, fruits, and legumes	Reduced soil amendment costs, potential revenue from by-product sales	Enhanced soil structure and fertility, increased microbial activity, reduced greenhouse gas emissions
Biogas slurry	Irrigation and soil conditioning	Field crops, forages, and grasslands	Reduced water and soil conditioner costs	Enhanced water retention, improved soil structure

Table 2 illustrates the utilization of dairy waste in organic agricultural production, highlighting its benefits, applications, and outcomes.

I. Table 2 categorizes different forms of dairy waste, encompassing dairy manure, dairy by-products (including whey and skim milk), and dairy slurry.

II. The table delineates the potential repurposing of various dairy waste types for organic agricultural practices. Dairy waste serves as a natural fertilizer for crops and also aids in improving soil, which helps the soil to produce more crops in the following cycle. Moreover, the dairy slurry is appropriate for drainage and soil enrichment.
III. The third column shows crops and vegetables that benefit from the use of dairy waste. Depending on how the dairy waste is used, this includes vegetables, fruits, legumes, field crops, forages, and grasslands.
IV. The table illustrates possible cost reductions that could result from using fertilizer made from dairy waste in the agricultural field. The reuse of dairy fertilizers, soil conditioners, or water sources minimizes farmers' consumption of synthetic inputs and deep well water, chemical fertilizer, and additive costs.
V. The table demonstrates how dairy waste benefits organic farming in light of achieving sustainability for the farm. This includes better resource utilization, reduced waste, enhanced soil fertility, higher crop yields, lower chemical inputs, improved water retention, and reduced greenhouse gas emissions. Integrating farm waste into organic agricultural processes enables farmers to achieve sustainable and environmental stewardship.

Dairy Process Model

Shamsuddoha et al. (2023) developed a model based on a sustainable supply chain framework for dairy farming operations [4]. Later, further development was examined based on eco-efficient dairy waste development [31]. Moreover, extended research has also been conducted to examine the integration of a circular economy and reverse logistics to achieve sustainable dairy operations [4]. For this research, we focused on organic development through sustainable dairy operations where agricultural crops (paddy, corn, and green grass) are considered for market demands and sustainable outcomes. The simulation model below further extends the agricultural outputs by considering biofertilizer production through dairy waste management, which reduces the challenges created by harmful chemical fertilizers, pesticides, and insecticides. Figure 1 develops a conceptual model relating organic agricultural and dairy production processes. The model starts by arranging the raw materials for dairy operations, followed by waste generation, waste process, technology incorporation, and agricultural land cultivation with organic substances. At the same time, the model incorporates sustainable guidelines for dairy operations and waste management. Such guidelines can help the farm achieve sustainable economic, social, and environmental outcomes.

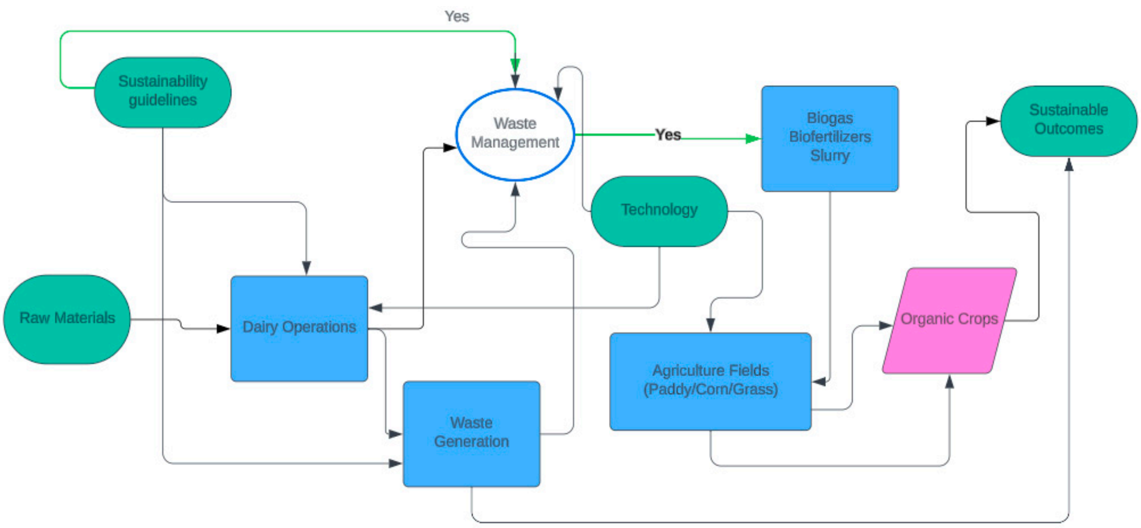

Figure 1. Conceptual model of dairy process with organic agriculture.

Figures 1 and 2 are based on the previous study by Shamsuddoha et al. (2024). The previous simulation model extended organic agricultural production in light of innovative farming methods for scientific waste management. Figure 2 depicts a dynamic systems model of a case dairy farming and farming atmosphere, emphasizing milk production, waste disposal, fertilizer utilization, and financial benefits. When cattle grow and mature, they produce milk, which flows into value-added activities like milk products including pasteurized milk, yogurt, card, butter, and flavored milk. The system includes cow age, culling, and dairy waste creation over time. Then, cow waste is converted to biogas and biofertilizer production, creating a feedback loop for the sustainable utilization of resources.

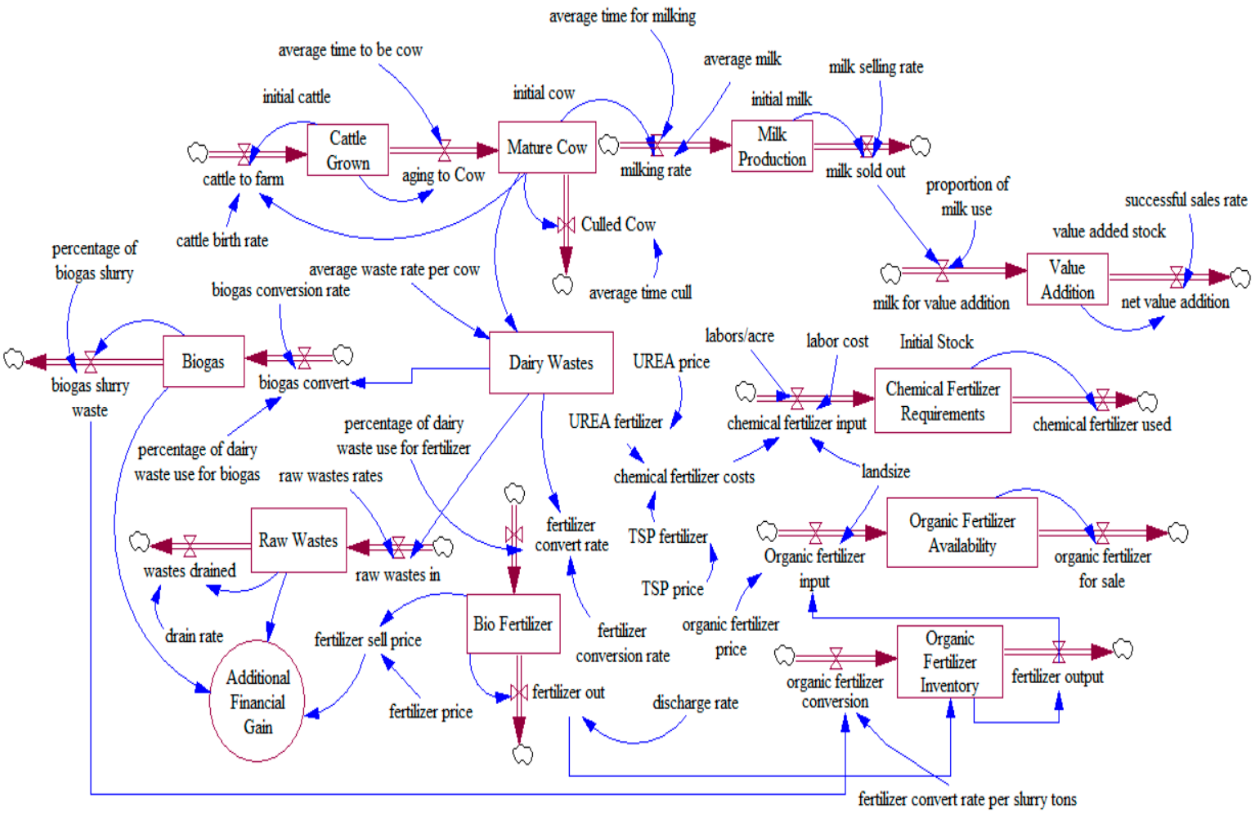

Figure 2. Simulation Model of a dairy model along with waste management. (Extended from a previous study [4,31].

The subsequent phase transforms waste into organic and chemical fertilizers and leftover raw wastes. The conversion of dairy waste into biogas and organic fertilizer positively impacts organic crop farming in the adjacent areas owned by the farms. If the by-product quantity is more than the required quantity, then the farm sells these valuable resources to other agricultural farms. Unconverted raw wastes flow to another stream, like landfilling or the irrigation of crop lands. The model also incorporates chemical fertilizer specifications, labor costs, and biofertilizer market prices to represent the system economics. Nutrients, fertilizers, and financial returns indicate a circular economy that recycles resources and minimizes waste to balance environmental and economic viability. At the same time, the process can contribute to social welfare, such as animal welfare, workers' facilities, and the generation of employment opportunities.

Figure 3 compares the current and improved processes for biogas and biofertilizers over a 60-month timeframe. The left graph indicates a substantial rise in biogas output under the improved process, which was nearly 20,000 tons per month by month 60, compared to roughly 5000 tons per month with the current approach. Similarly, the right graph shows an impressive rise in biofertilizer production in the improved process, with an output of roughly 80 tons per month, contrasted to the current production rate of about twenty tons per month. The farm's waste-handling procedural improvements emphasize the potential for higher resource utilization and efficiency advancements.

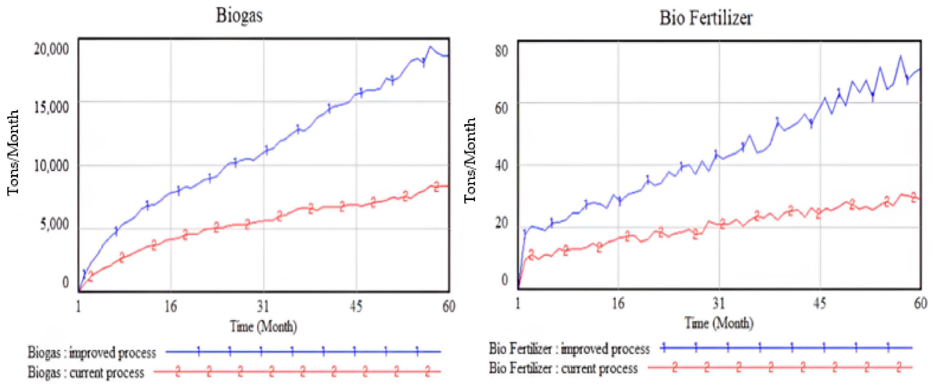

Figure 3. Simulated results for biogas and biofertilizer productions in five years.

Figure 4 shows the amount of organic fertilizer in stock and how much can be produced in the current process versus an improved method over 60 months. The left graph demonstrates that the improved process greatly increases the quantity of organic fertilizer obtainable, reaching about 2000 tons per month. The conventional process remains below 500 tons per month. The right graph illustrates a significant rise in the money that can be gained through selling organic fertilizers. With the updated method, it is over 1.5 million dollars, whereas with the conventional method, it is just over $500,000. Consequently, the improved process of making more organic fertilizers renders them more valuable, supporting modern farming processes that benefit the surrounding environment and earn a more significant profit.

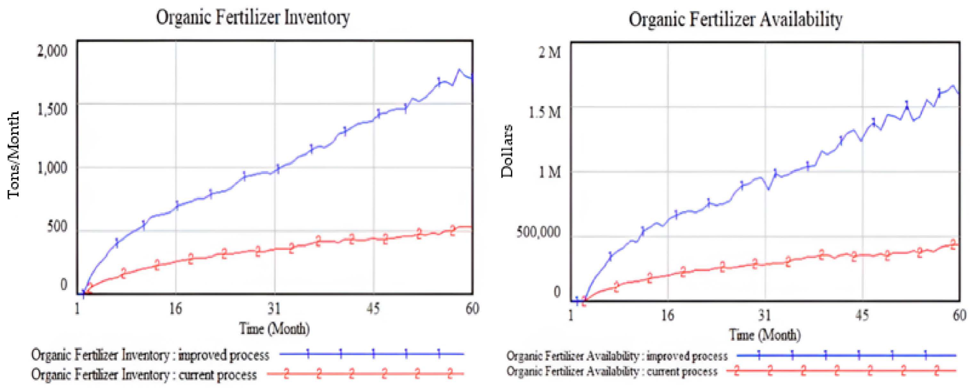

Figure 4. Simulated results for organic fertilizer inventory (tons) and availability (dollar value).

Figure 5 demonstrates the value addition and raised earnings flowing from an upgraded process against the current one. The left graph demonstrates that compared to the existing method, which continues to produce monthly returns under $50,000, the improved approach yields an even higher gain of nearly $150,000 in five years. In contrast to the existing process, the improved process retains a higher output, which signifies a more effective utilization of resources and thus economic success. The right graph, which shows value addition, compares the performance of the current and improved processes. It is visible that the simulated results are better for the improved process than the current process.

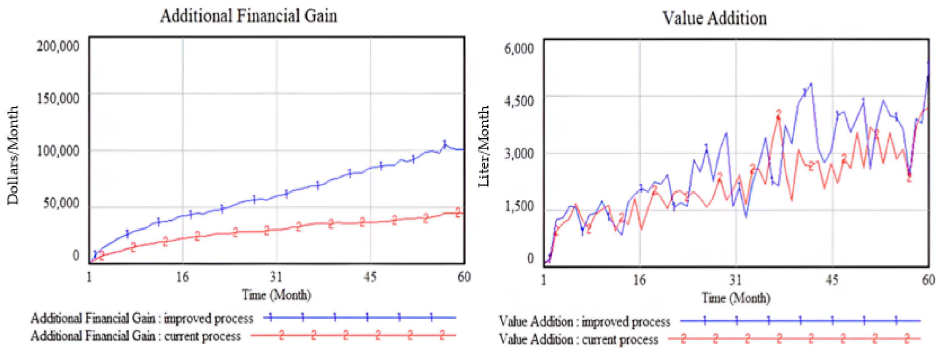

Figure 5. Simulated results for financial gains and value addition.

Figure 6 represents a comparison of dairy waste and raw waste production between the improved and current processes. The left graph demonstrates that dairy waste accumulation under the improved process increases progressively to nearly 600 tons/month. On the other hand, the current process produces below 300 tons of waste per month. Similarly, the right graph illustrates raw waste accumulation after utilizing wastes for biogas and biofertilizers. Under the improved approach, the compilation reaches nearly 500 tons per month, almost double the amount achieved by the current process. Such improvements demonstrate the boost in waste generation and collection efficiency due to proper management and productivity.

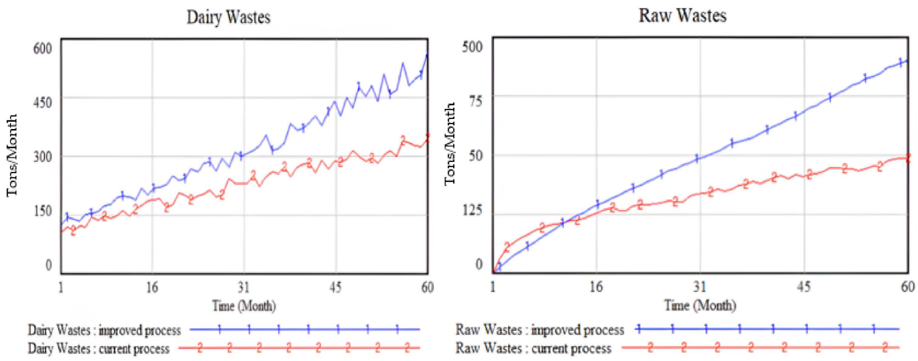

Figure 6. Simulated results for accumulated dairy wastes and raw wastes.

5. Discussions

Table 3 highlights the various benefits of integrating organic concepts with dairy farming, emphasizing the support for both environmental and economic sustainability. The use of dairy waste as fertilizers and irrigation helps reduce waste and enrich resource enhancements and allocations to organic practices using improved processes. Such an improved process promotes healthier soil and reduces the environmental impact of agricultural operations, especially on crop production and soil health, for the next production cycle. Also, dairy manure is vital in improving soil quality and reducing water contamination and wastage. Such practices enhance microbial activity, supporting crop development and overall agricultural productivity.

This approach reduces soil and water pollution, decreases greenhouse gas emissions, and enhances ecosystem health by dealing with chemical residues, which helps ensure long-term sustainability. Animal welfare is additionally improved by making ethical farming practices, such as supplying animals with pasture access, a top priority. As a result, quality dairy products attract millions of customers who recognize that healthy nutrition is produced responsibly and sustainably. Farmers currently have more significant opportunities to diversify their sources of income and achieve higher prices because of the rising demand for organic products. Consequently, the amalgamation of organic and dairy farming promotes economic growth and protects the environment, offering a sustainable and well-rounded farming approach.

Table 3. Key sustainable benefits of integrating dairy farming with organic agriculture.

Aspects	Details
Integration of Dairy Farming and Organic Agriculture	Improves sustainability, soil health, and product quality through nutrient recycling and resource efficiency by using dairy waste as fertilizers and irrigation.
Enhancing Soil Fertility and Health	Utilizes dairy manure to improve soil structure, water retention, and microbial activity, fostering crop development.
Reducing Chemical Inputs and Environmental Impacts	Eliminates synthetic chemicals, reduces soil, saves water consumption, decreases pollution greenhouse gas emissions, and improves ecosystems.
Improving Animal Welfare and Product	Quality emphasizes animal welfare with pasture access and ethical standards, producing high-quality, sustainable dairy products.
Market Opportunities and Consumer Demand	It meets growing consumer demand for organic products, offering farmers higher prices and diversification opportunities.

A sustainable dairy industry provides some positive and negative aspects. For example, transitioning to organic status requires time and money, since farmers must fulfill rigorous production standards and undergo certification inspections. Organic dairy waste disposal needs careful planning and implementation to prevent environmental problems. Sustainable dairy farming promotes sustainability and product quality. For the protection of the environment, welfare of animals, and consumer trust in organic dairy goods, farmers may utilize organic crop development through proper implementation of planning, organic standards, and ecological farming.

5.1. Theoretical and Practical Contributions

The study contributes theoretical and practical viewpoints.

5.2. Theoretical Contributions:

1. Advance in Agroecological Theory: Demonstrates the synergies between livestock and crop systems by applying ecological principles to optimize resource use, improve soil health, and foster biodiversity.
2. Development of Sustainable Agriculture Frameworks: The improved process aligns with sustainability frameworks through holistic management, regenerative practices, and ecosystem-based solutions.
3. Integration of Livestock and Crop Interactions: Enhances theoretical models by focusing on nutrient cycling, soil fertility management, and ecological balance.

5.3. Practical Contributions

1. Improved Agricultural Sustainability: Optimizes resource use, minimizes environmental impacts, and enhances economic viability, promoting long-term farm resilience.
2. Enhanced Soil Fertility and Productivity: Dairy waste is used as a fertilizer and soil conditioner to improve soil structure, water retention, and crop yields, reducing dependence on synthetic inputs.
3. Minimized Environmental Impact: Reduces chemical inputs, lowers greenhouse gas emissions, and promotes biodiversity conservation.
4. Market Opportunities and Economic Advantages: Higher market prices for organic dairy products boost profitability, diversify revenue streams, and enhance farmers' economic resilience.

6. Conclusions

Integrating dairy farming with organic methods could improve dairy sustainability, profitability, and efficiency. Producers can improve resource utilization for surrounding paddy and corn fields, soil health, and mitigate other environmental issues. The integration influences agroecological theory, sustainable agriculture systems, and livestock-crop interactions in farming systems. Integrating dairy farming with organic farming also minimizes environmental consequences and expands sources of revenue. This approach increases crop production, preserves soil nutrients, and increases biogas and organic fertilizer production to reduce environmental adverse impacts. Through the utilization of dairy waste and organic concepts, farms can satisfy the demand for organic dairy goods, charge premium prices, and enhance economic resilience. Effective integration involves dealing with organic certification, dairy waste management, and organic regulations. Integrating dairy farming with conventional farming could render the dairy business more sustainable, resilient, and environmentally beneficial. Such practices will impact long-term sustainability in light of environmental, economic, and social welfare through diligent planning, innovative farming techniques, and stakeholder collaboration.

7. Study Limitations and Future Research Prospects

This research provides valuable knowledge regarding managing dairy waste for agricultural use to achieve sustainability, despite some limitations. The data collection scope remained confined to a specific case study, limiting its capacity to explore the bigger picture of the dairy industry. In light of time constraints, the study was not sufficiently comprehensive in investigating all of the environmental variables like regulations, community circumstances, local facilities, weather perspectives, budgeting constraints, employee efficiency, knowledge, and market mechanisms' real impacts on the findings. Long-term forecasts, which could provide a deeper understanding of economic sustainability, were also missing from the assessment. Future studies will attempt to verify these missing findings using extensive field research in various regional and weather conditions settings. Integrating innovative waste treatment techniques within the dairy industry through further process development could improve environmentally friendly outcomes. To acquire an extensive global perspective, it is also important to scale up and evaluate methods practiced across different farming systems and examine macroeconomic consequences, stakeholder versatility, and favorable policy frameworks.

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