Proceedings of the 5th International Conference on Environmental Science and Applications (ICESA 2024)
Lisbon, Portugal- November 18 - 20, 2024
Paper No. 147
DOI: 10.11159/icesa24.147

Comparative Analysis of Sustainable Cattle Manure Management Alternative Practices in Kuwait

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Abstract **-** This study addresses the environmental and economic challenges posed by cattle manure management in Kuwait, emphasizing the transition from traditional practices like pasture spreading to more sustainable alternatives such as composting and anaerobic digestion. The research highlights the substantial environmental impacts of current practice, including significant greenhouse gas emissions and potential groundwater contamination. Through comprehensive comparative analyses, alternative methods such as composting, anaerobic digestion, incineration, and gasification are evaluated for their environmental efficiency, operational complexity, and social acceptance. Composting and anaerobic digestion are identified as superior alternatives due to their ability to mitigate environmental impacts, enhance soil health, and contribute to energy production. The study also discusses the economic implications of these methods, detailing the initial and operational costs associated with each technology. Finally, policy recommendations are provided to promote the adoption of these environmentally friendly practices.

Keywords**:** Cattle Manure Management – Composting - Anaerobic Digestion – Incineration – Gasification - Environmental Impact - Kuwait

1. Introduction
1.1. Global Animal Waste Issue
Animal waste, particularly cattle manure, is a critical global issue with significant environmental, economic, and social implications. According to the Food and Agriculture Organization (FAO), livestock manure can be both a valuable resource and a potential environmental pollutant if not managed properly [1]. Effective management of cattle manure is essential to mitigate its environmental impact and harness its potential benefits.

1.2. Impact of Cattle Manure on Environment and Economy
Cattle manure contributes to several environmental issues, including the emission of greenhouse gases (GHGs) such as methane and nitrous oxide, which intensify climate change. Methane emissions from enteric fermentation and account for a significant portion of livestock-related GHGs [1]. Nitrous oxide emissions primarily result from manure management practices involving the application of manure to land [2].

In addition to GHG emissions, improper management of manure can lead to water pollution through nutrient runoff, which can cause eutrophication of water bodies [3], [4]. This nutrient pollution can severely impact aquatic ecosystems, leading to algal blooms and hypoxic conditions that threaten marine life [3], [4].

Economically, manure management represents a cost for farmers, but it also offers opportunities for resource recovery through composting, and biogas production. Properly managed manure can be a valuable fertilizer, improving soil health and reducing the need for synthetic fertilizers [5], [6]. Biogas production from anaerobic digestion of manure provides a renewable energy source, contributing to energy security and reducing dependence on fossil fuels [7].

2. Current Cattle Manure Management Practices
2.1. Spreading on Pasture
Spreading manure on pasture is the primary method used to dispose of cattle manure in Kuwait. This practice involves directly applying manure to fields as a fertilizer. While it is a straightforward and cost-effective option, it has significant

environmental drawbacks if not managed properly. Improper spreading can lead to nutrient runoff, causing water pollution and eutrophication of water bodies. Additionally, this practice can contribute to methane emissions, a potent greenhouse gas that significantly impacts climate change [8], [9]. It also poses health risks to the farmers handling the manure, including respiratory issues and other health concerns [10].

3. Alternative Manure Management Methods

3.1. Composting

Composting is a biological process that decomposes organic waste into a stable, nutrient-rich soil additive. It reduces the volume of manure and produces valuable compost for agriculture. Proper management is essential to avoid issues such as odor, pests, and incomplete decomposition [11]. According to [6], [11], composting cattle manure can significantly reduce pathogen levels and improve soil health when used as a fertilizer

3.2. Anaerobic Digestion

Anaerobic digestion is a process that breaks down organic waste in the absence of oxygen to produce biogas (a mixture of methane and carbon dioxide) and digestate (a nutrient-rich slurry). This technology can generate renewable energy and reduce greenhouse gas emissions. The digestate can be used as a fertilizer, further enhancing the environmental benefits [4], [5], [12].

3.3. Incineration

Incineration involves burning manure at high temperatures to reduce its volume and generate energy. While it can significantly reduce the amount of waste sent to landfills, it produces emissions that must be carefully controlled to avoid air pollution. Incineration can reduce manure volume by up to 90%, making it an effective volume reduction strategy [13]. However, it is associated with the release of pollutants such as dioxins and furans, which need to be managed carefully [14].

3.4. Gasification

Gasification is a process that involves the thermal decomposition of manure at high temperatures (800-1400°C) in an oxygen-limited environment, producing a combustible gas (syngas) comprised of carbon monoxide, hydrogen, and methane. This syngas can be used directly for heating or power generation, or as a feedstock for producing chemicals. Unlike incineration, gasification results in lower emissions of particulates and harmful gases, making it a cleaner technology. It also allows for the recovery of energy in a more flexible and efficient manner, enhancing the overall energy output from the waste material. Gasification is a versatile technology that can handle various types of waste, but it requires significant investment and sophisticated technology to operate effectively [12].

Table 1 provides a detailed comparative analysis of various manure management technologies, highlighting their advantages, disadvantages, and associated methane emissions, illustrating the trade-offs between cost, environmental impact, and operational complexity.

Table 1: Comparative Analysis and Methane Emissions of Manure Management Technologies.

Manure Management Practice	Advantages	Disadvantages	Methane Emissions (kg CO2e/ton)	Reference
Spreading on Pasture	Low initial cost, simple operation	High GHG emissions, potential groundwater contamination	2.2 -12	[15]
Composting	Reduces waste volume, produces valuable compost	Requires proper management to avoid odor and pests	8.92	[3]
Anaerobic Digestion	Generates renewable energy, reduces GHG emissions	Moderate initial investment, complex technology	218 (m^3 gas yield)	[5]

Incineration	Significant volume reduction, energy generation	High emissions, High initial investment	0.0046-0.26	[14]
Gasification	Produces syngas for energy production, versatile for other related wastes	High investment, sophisticated technology	-	[16]

4. Case Study: Cattle Manure Management in Kuwait
4.1. Current Situation

In Kuwait, the management of cattle manure presents a significant environmental challenge, particularly in the Sulaibiba agricultural area of Jahra Governorate, where all 52 cattle farms in the country are located. These farms, each covering at least 5,000 square meters, collectively house approximately 22,443 cattle, according to the 2024 report from the Public Authority of Agriculture Affairs and Fish resources (PAAF). The herd sizes vary significantly, ranging from as few as 15 to as many as 2,712 cattle per farm[17].

The composition of these herds is diverse, with dairy cattle making up the largest portion at 45%, followed by growing calves (females) at 21%, and dry cows at 18%. The remaining herd consists of baby calves (females), growing calves (males), baby calves (males), and bulls, which together account for 16% of the total cattle population (Figure 1)[17].

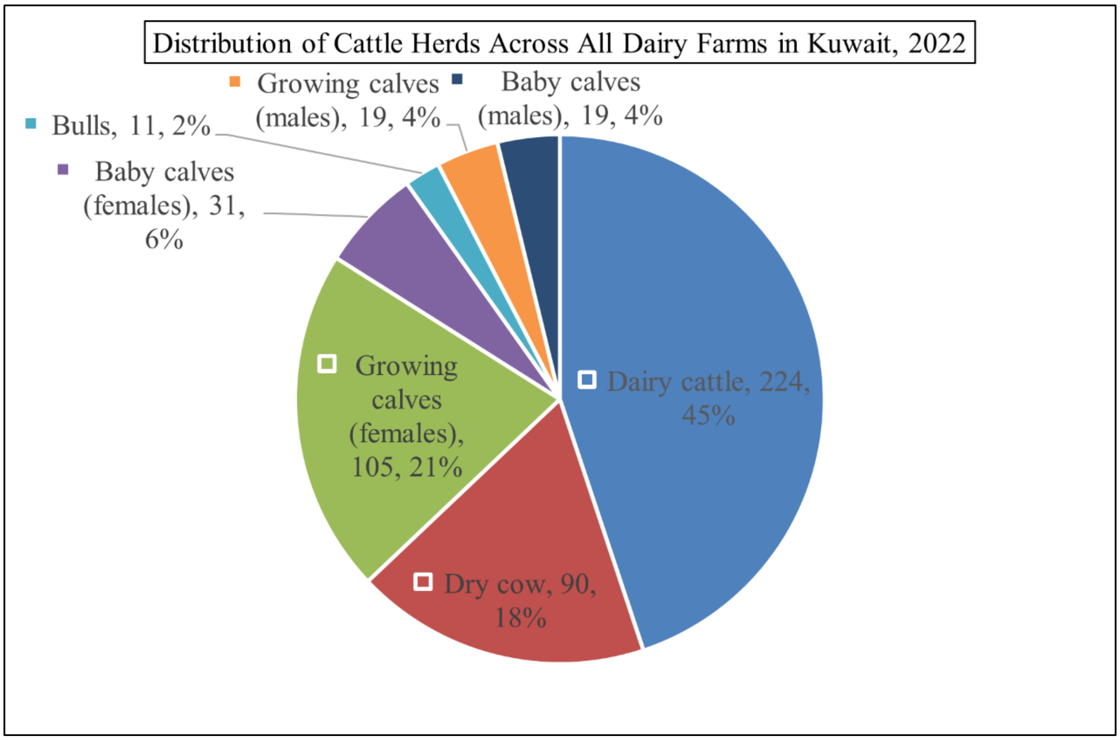

Fig. 1: Distribution of Cattle Herds Across All Dairy Farms in Kuwait, 2022[17]

Over the past 28 years, there has been a steady increase in both the cattle population and the volume of manure produced. Current estimates indicate an annual manure production of approximately 112,215 cubic meters, equating to about 5 cubic meters per head per year[17]. This trend is clearly illustrated in Figure 2, which shows the annual manure volume rising in parallel with the cattle headcount, particularly notable from the early 2000s onwards. The increasing volume of waste underscores the urgent need for effective management strategies to mitigate its environmental impact.

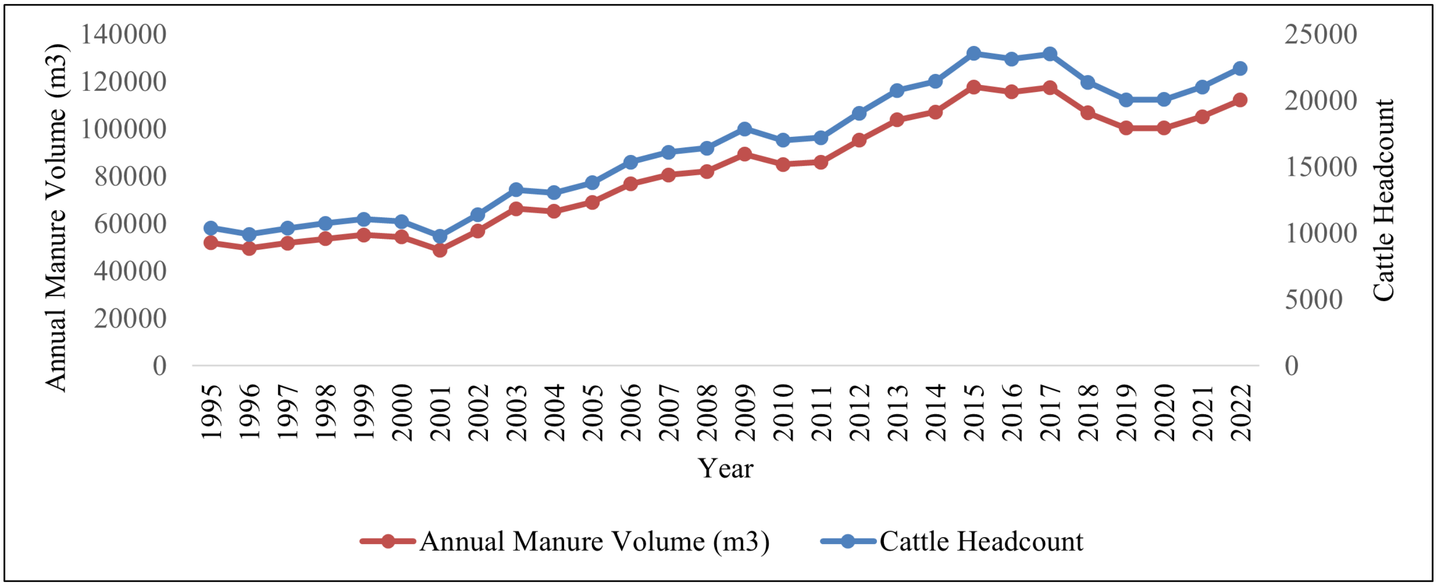

Fig. 2: Annual Trends in Cattle Population and Manure Production in Kuwait (1995-2022)[17]

At present, the primary practice of spreading manure on pasture exacerbates environmental issues, particularly through the release of methane, a potent greenhouse gas confirmed by both EPA and local studies as a significant source of biogenic methane[18], [19]. Additionally, this practice poses serious risks to groundwater quality due to nutrient leaching, which threatens both water resources and soil health[10], [20]. These challenges highlight the critical absence of sustainable manure management practices in Kuwait.

5. Technical and Operational Considerations

Composting and anaerobic digestion are mature technologies with well-established operational practices. They require proper management and infrastructure to ensure efficient and effective waste processing. For instance, composting typically involves maintaining temperatures between 55°C and 65°C to promote microbial activity and pathogen reduction, resulting in a stable end product in about 8-12 weeks [1], [11], [21]. Anaerobic digestion, on the other hand, requires precise control of parameters such as pH (6.8-7.2), temperature (35-55°C), and hydraulic retention time (15-30 days) to optimize biogas production [6], [10], [21].

Incineration and gasification are more complex and require sophisticated technology and significant investment. Incineration operates at high temperatures (850-1000°C), reducing waste volume by up to 90% and generating about 2-5 MJ of energy per kg of manure[13], [14], [21]. Gasification, on the other hand, is a process that involves the thermal decomposition of manure at high temperatures (800-1400°C) Unlike incineration, gasification results in lower emissions of particulates and harmful gases, making it a cleaner technology.

6. Social Acceptance

Public acceptance of waste management methods is crucial for their success. Composting and anaerobic digestion are generally more acceptable to the public due to their environmental benefits and lower pollution risks. Composting can reduce greenhouse gas emissions compared to spread on pasture and is seen as a sustainable way to manage organic waste while producing valuable soil amendments [22]. Anaerobic digestion is favored for its ability to produce renewable energy and reduce waste volumes, with public support often tied to its perceived environmental benefits and potential for local energy generation [23].

In contrast, incineration and gasification face greater public resistance due to concerns about air pollution and health impacts. Emissions from incineration, including dioxins and furans, raise significant health concerns despite modern pollution control technologies [12]. Gasification, while efficient, also requires careful management of by-products and emissions, which can deter public support [23]. Public awareness campaigns and transparent communication about the benefits and risks of these technologies are essential to improve acceptance.

7. Proposed Solutions for Effective Cattle Manure Management in Kuwait

7.1. Implementing Sustainable and Environmentally Friendly Alternatives

Given the significant environmental and health drawbacks associated with spreading manure on pasture, it is essential to adopt more sustainable and environmentally friendly manure management practices. Composting emerges as a viable alternative, reducing the volume of manure and producing nutrient-rich compost that enhances soil health. Similarly, anaerobic digestion offers substantial advantages by generating renewable energy in the form of biogas and producing a nutrient-rich digestate for use as fertilizer. Despite the higher initial investment compared to spreading on Pasture, the long-term reduction in greenhouse gas emissions and energy production justify its adoption.

Table 4 provides a detailed comparison of the costs and benefits associated with different manure management methods, highlighting the initial investment and operating costs.

Table 4: Costs of Different Manure Management Practices.

Manure Management Method	Initial Investment Cost ($/ton)	Annual Operating Cost ($/ton)	References
Spreading on Pasture	3-8	-	[2]
Composting	10-31	-	[3]
Anaerobic Digestion	500-3000	20-50	[5]
Incineration	15,797	<4% of capital cost	[8], [14]
Gasification	50,000-150,000	<10% of capital cost	[2], [16]

7.2. Policy Recommendations

To facilitate the adoption of these alternatives, it is crucial to conduct a thorough a further evaluation to assess the feasibility of each method in the context of each farm conditions and resources. Developing the necessary infrastructure and capacity, along with investing in training, will support the implementation of these technologies. Promoting public awareness and acceptance through education and outreach is essential to highlight the benefits and address any concerns regarding new technologies. Additionally, implementing supportive policies and incentives, such as subsidies, tax incentives, and regulatory frameworks, will encourage the adoption of environmentally friendly manure management practices[1], [24].

8. Conclusion

In conclusion, the exploration of alternative sustainable cattle manure management practices in Kuwait presented in this study underscores the importance of transitioning from spreading on pasture to more environmentally friendly and socially acceptable alternatives. Composting and anaerobic digestion emerge as superior options due to their dual benefits of mitigating environmental impact and enhancing resource recovery. These methods align well with sustainable agricultural practices, enhancing soil health and reducing reliance on synthetic fertilizers. It is crucial for policy makers to support this transition through incentives and regulations that facilitate the adoption of sustainable practices, ultimately contributing to a more sustainable agricultural sector in Kuwait. That could set a precedent for the GCC region and worldwide, contributing to global efforts in sustainable waste management and environmental conservation.

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