Chapter 8

Sustainable Animal Manure Management Strategies and Practices

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Additional information is available at the end of the chapter

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Abstract

Animal manure is a valuable resource if handled responsibly but a source of serious challenges and public health concerns if managed inappropriately. Risks associated with animal manure handling could be related to soil, water and air quality. In spite of this, non-sustainable animal manure management practices are still common in some places. Sustainable management of animal manure requires multi-prong approaches and holds several benefits both to the farmers and the general public. The importance attached to the handling and management of manure in several countries has led to the enactment of relevant legislations, regulations, standards and policies to promote sustainable handling of animal manure. Some of these are enacted at community, state, national, regional and international levels. Several techniques ranging from simple, low-cost to complex strategies are available for proper handling of animal manure. The proposed chapter will highlight some unsustainable animal manure handling practices. It will discuss some of the risks associated with irresponsible handling of animal manure as well as some of the measures to promote sustainable animal manure management.

Keywords: animal, manure, sustainable, management techniques, regulations

1. Introduction

Animal agriculture is important to global food, nutrition and economic security. In many countries, domestic animal agriculture consists of mainly ruminants, non-ruminant and aquatic animals. Examples are cattle, swine, poultry and companion animals. Animal agriculture plays a critical role in the economic and social lives of the populace through its contribution to nutritious food supply, job creation, income generation and household earnings, asset saving, economic output and taxes, agricultural diversification, animal traction, soil fertility and transportation [1, 2]. Meeting the food needs of the growing world population which is estimated to be over 9 billion by 2050 is one of the greatest challenges facing animal agriculture the world over. Increasing food production is not as straightforward as simply increasing production capacity. There are constraints such as land and water use, environmental impact of animal agriculture and regulations which may limit the ability of producers to simply add enough animals to meet future demand for foods of animal origin. Therefore, animal agriculture must be carried out in a way that does not jeopardize the future use of natural resources while attempting to meet the food needs of man and animals.

Animals are raised primarily for food and non-food purposes such as companions, leather and even manure in some production systems [3]. By-products, which may constitute wastes if not managed appropriately, are generated in the process of producing, processing, transporting and marketing animals. Some potential wastes generated during animal production operations include waste or left-over feed, wastewater, hatchery wastes, abattoir wastes and manure. Manure from animal production often has external contributor such as beddings, urine, wash water, precipitation, spilled feed and spilled water [4]. Prior to the introduction of organic fertilizers, animal manure played the central role in enhancing soil fertility. In spite of the role of organic fertilizers in agricultural production, manure remains an important fertilizer resource especially in areas where organic fertilizers are not readily available or accessible to farmers.

The intensification of animal operations has led to the production of a considerable amount of manure concentrated in a particular location in excess of the need and may become a liability. The estimated total manure nitrogen production increased from 21.4 TgN/year in 1860 to 131.0 TgN/year in 2014 with an overall significant increasing trend during 1860–2014 (0.7 TgN/year, $p < 0.01$) [5]. Intensive animal production, therefore, can be significantly problematic with respect to waste storage and removal. Air and water pollution associated with animal manure has been at the centre of several regulatory discussions across the world. Animal manure contains a wide range of micro-organisms which could be a source of hazards to humans and animals. These micro-organisms can cause food contaminations and epidemics and therefore dangerous to public health. In fact, several foodborne illnesses around the world have been linked directly or indirectly to manure contamination. To therefore limit some of the challenges associated with animal manure handling, sustainable manure management practices and strategies are advocated. It is critical that manure management plans form an integral part of the animal production strategy. These include legislations and other legal instruments as well as other innovative practices that reduce the risks of exposure. Many manure management strategies and technologies are applicable to a wide range of production environment and scales. The adoption of sustainable manure management technologies holds a lot of direct and indirect benefits to the society. These include contributions to a clean environment, pollution reduction, job creation and the protection of biodiversity. This chapter gives an overview of sustainable animal manure management practices and strategies.

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2. Characteristics of animal manure

Manure contains many useful and recyclable components (**Table 1**). The physical and chemical characteristics of animal manure will impact its potential use particularly as a fertilizer and the ease with which it would be handled. Animal manure can be categorized based on their consistency or moisture content into liquid manure (up to 5% solids), slurry and semi-solid manure (between 5 and 25% solids) and solid manure (more than 25% solids) [6]. The general characteristics of manure generated from typical animal production operations are presented (**Table 2**). In view of high variability in consistency, physical structure and chemical composition of animal manure from one location to the other, preference should be given to locally derived manure characteristics.

Manure component	Beneficial uses	Advantages
Nutrients	Compost, fertilizer, biomass conversion (animal feed, soil amendments, fertilizer, etc.)	Cost savings on fertilizer and income generation from sales of manure
Organic matter	Soil amendments/structuring	Improves soil structure and water holding capacity; impacts on crop yield
Solids	Bedding	Savings on cost of bedding materials, e.g., up to $50/cow/year
Energy	Biogas, bio-oil, and syngas	Supplementary energy for farm use; reduced reliance on fossil fuels; income generation from sales of energy
Fiber	Peat substitute, paper, and building materials	Potential environmental liability turned into useful commodities

Source: Adapted from [7].

Table 1. Beneficial uses of manure.

Category of animal	Weight (lb)	Moisture (%)	Total solids (lb)	Volatile solid (lb)	Biological oxygen demand (lb)	Nitrogen (lb)	Phosphorus (lb)	Potassium (lb)
Dairy manure								
Lactating cow	97–130	87	12–17	9.2–13	2.1	0.66	0.11–0.15	0.30–0.38
Calf	83	83	9.2	7.7	—	0.42	0.05	0.11
Heifer	56	83	8.5	7.3	1.2	0.27	0.05	0.12
Dry cow	51	87	6.6	5.6	0.84	0.30	0.042	0.10
Beef manure								
Beef cow in confinement	104	88	13	11	2.5	0.35	0.08	0.25
Growing calf in confinement	77	88	9.2	7.7	1.7	0.45	0.08	0.29

Category of animal	Weight (lb)	Moisture (%)	Total solids (lb)	Volatile solid (lb)	Biological oxygen demand (lb)	Nitrogen (lb)	Phosphorus (lb)	Potassium (lb)
Finishing cattle	65	92	5.2	4.3	1.0	0.36–0.50	0.044–0.076	0.25
Swine manure								
Gestating sow	25	90	2.5	2.3	0.84	0.16	0.05	0.11
Lactating sow	59	90	5.9	5.4	2.0	0.45	0.13	0.28
Boar	19	90	1.9	1.7	0.66	0.14	0.05	0.09
Poultry manure								
Layers	57	75	15	11	3.3	1.1	0.33	0.39
Broiler	88	74	22	17	5.3	0.96	0.28	0.54
Turkey toms	34	74	8.8	7.1	2.3	0.53	0.16	0.25
Turkey hen	48	74	12	9.8	3.0	0.72	0.20	0.31
Duck	102	74	27	16	4.5	1.0	0.35	0.50

Source: ASABE [8]; Barth et al. [9].

Table 2. Characteristics of manure of farm animals (per 1000 lb. animal unit per day).

3. Animal manure management systems

The animal waste management system can be described as a planned system with relevant components installed and managed to control and use by-products of animal production in a way that sustains and enhances the quality of air, water, soil, plant and animal resources (adapted from [10]). Animal manure management system is an integral part of the agricultural waste management system. Animals are raised under different systems of production and this influences the manure management systems and strategies adopted. Manure produced by animals managed in range and pasture lands is usually managed using strategies that are different from those employed for animals raised in confinement. Manure management is important because it significantly reduces the risks associated with manure handling and utilization. An efficient manure management system will limit or prevent manure or its constituents from gaining undesirable access to the larger environment. Sound manure management contributes to health and environmental, economic and social benefits (**Table 3**). A resource-efficient, socially inclusive and low-carbon economy is achieved by tapping into waste as a resource, extending the life cycle of valuable materials and increasing the use of secondary materials [11].

Establishing the goals of animal manure management systems is critical to its successful planning and implementation. The objectives of a manure management system could range from limiting the environmental impacts of manure handling, limiting manure nutrient losses and promoting its efficient use to regulatory compliance, regulating the timing of use in sync with the other uses of the manure resources and the generation of income.

Sustainable development pillar	Associated benefit of sound manure management
Environment	• Prevents the environmental impacts on air, water, soil, wildlife and the marine • Protects human health in communities and at waste management facilities • Minimizes the risks associated with the waste • Improves occupational health • Reduces greenhouse gas emissions from waste • Reduces litter and odor • Prevents the risks of flood
Economy	• Increases business opportunities • Contributes to GDP • Provides savings to businesses, especially in resource extraction and use, by waste prevention actions, recovery and/or recycling activities • Achieves economic savings by improvements in human health and the environment, leading to higher productivity, lower medical costs, better environmental quality and the maintenance of ecosystem services.
Social	• Creates employment, including low, medium, and high-skilled jobs • Integrates and professionalizes employment in the informal sector (the route to addressing equity and poverty issues) • Delivers more attractive and pleasant human settlements and better social amenity • Encourages changes in community attitudes and behaviors.

Source: Adapted from [11].

Table 3. Environmental, economic and social benefits of sound manure manage management.

Several methods of manure management systems have been identified. Each system of manure management also has its own challenges particularly with the nutrient management (**Table 4**). The primary nutrients of concern as it affects animal manure are nitrogen, phosphorus and potassium largely due to their importance in soil application. The concerns are associated with potential nutrient losses in storage and during handling as well as potential nutrient overload during land application. Due to limited land availability and lack of nutrient test to determine requirements before applications, soils applied with manure tend to have excess nitrogen and phosphorus [12]. The evidence of considerable losses of manure nutrients in storage is abundant [13] (**Table 5**). The basic functions of production, collection, storage, treatment, transfer and utilization associated with manure management systems must, therefore, be managed holistically to minimize nutrient losses, prevent pollution and other potential risks [10].

In view of the variation in the situations in which the waste management system is incorporated, as a guide, the decision-makers' concerns, needs and objectives must be considered in planning the animal waste management system; the characteristics and annual production of the waste that would require management as well as potential future changes in the size of operation must be determined; the alternatives the decision-maker is willing to consider for utilization must be determined; the landowner's preference for equipment and location of the facility must be determined; and the design of the system should cover from the production to the utilization function level and must be put in place [9]. These considerations are germane to planning and designing the waste management systems for dairy, beef, swine, poultry and other animals.

Type of system	Description	Associated nutrient loss challenges
Grazing	Animals deposit manure directly on the field during grazing	Substantial nutrient losses especially nitrogen occur through leaching and volatilization
Kraals	Animals are kept in enclosed land area to be used for cropping in the future on rotational basis.	High losses of nutrients through leaching.
Dry lot storage	Manure and urine are captured using bedding materials	Substantial losses of nutrient could occur, particularly through urine. Leaching and surface run-off can also occur
Slurry storage	Urine and feces are stored together and the manure is usually in semi-liquid form	Volatilization losses are dependent on ventilation, depth of storage tanks and length of storage
Lagoon	Liquid manure are treated in anaerobic lagoon with or without the solids separated	Leaching through lagoon bottom, discharge into water surface and odor. High ammonia, and some methane and nitrous oxide emissions may occur
Fuel	Manure are either burnt directly as fuel or handled anaerobically for biogas production	Nitrogen, carbon and sulfur losses as a result of burning. High water content of slurry makes it difficult to handle
Others	These could include plastering for house construction and use as animal feed. These forms of uses are limited and the use of manure as animal feed is not encouraged	Manure used for construction is totally lost to agriculture.

Source: Adapted from [14].

Table 4. Examples of manure management systems.

Manure management system	Beef			Dairy			Swine			Poultry		
	N	P	K	N	P	K	N	P	K	N	P	K
Manure stored in open lot, cool, humid region	30–45	20–30	30–45	15–30	5–15	5–15	30–45	20–35	30–45	—	—	—
Manure stored in open lot, hot arid region	40–60	20–30	30–45	30–45	5–15	5–15	—	—	—	—	—	—
Manure liquid and solids in a covered, watertight structure	15–30	5–15	5–15	15–30	5–15	5–15	25–30	5–15	5–15	—	—	—
Manure liquid and solids in an uncovered watertight structure	25–40	10–20	10–20	25–35	10–20	10–20	25–30	10–20	10–20	—	—	—
Manure liquid and solids (diluted less than 50%) held in waste storage pond	—	—	—	20–35	5–20	5–20	—	—	—	—	—	—
Manure and bedding held in roofed storage	—	—	—	20–35	5–20	5–20	—	—	—	30–45	5–20	5–20
Manure and bedding held in unroofed storage, leachet lost	—	—	—	25–45	15–25	15–25	—	—	—	—	—	—
Manure stored in pits beneath slated floor	15–30	5–15	5–15	15–30	5–10	5–10	15–30	5–10	5–10	10–20	5–10	5–10

Manure management system	Beef			Dairy			Swine			Poultry		
	N	P	K	N	P	K	N	P	K	N	P	K
Manure treated in anaerobic lagoon or stored in waste storage pond after being diluted more than 50%	65–80	50–65	35–50	65–80	50–65	35–50	70–80	50–65	40–50	70–80	50–65	40–50

Source: Adapted from [15].

Table 5. Nutrient losses in various manure management systems (%).

Waste Management Hierarchy	Attribute	Applicability in animal manure management
Avoidance	Most preferred option. Preventive. Use of less hazardous materials in the design and manufacture of products. Develop strategies for cleaner and environmentally friendly production	While the production of wastes cannot be completely eliminated in animal production, the production can be made cleaner and environmentally friendly
Reduction of wastes	Second most preferred option. Preventive. Actions to make changes in the type of materials being used for specific products. This approach contributes to effective savings of natural resources	Applicable
Reuse	Predominantly ameliorative and partly preventive. The waste is collected during the production phase and fed back into the production process. Reduce the amount of wastes generated and the cost of production. Desirable.	Applicable
Recycle	Predominantly ameliorative and partly preventive. The waste materials are collected and processed, and used in the production of new products. The process prevents pollution. Desirable.	Applicable
Energy recovery	Predominantly assimilative and partly ameliorative. This is also called waste to energy conversion. Wastes are converted to usable energy forms such as heat, light, electricity, etc. Desirable.	Applicable
Treatment	Predominantly assimilative and partly ameliorative. Desirable.	Applicable
Sustainable disposal	Disposal is the least preferred option in the waste management hierarchy and should be avoided.	Possible but not preferred

Source: Adapted from [16].

Table 6. Waste management hierarchy and animal manure management.

The concept of waste management hierarchy can serve as a guide in the choice of the appropriate waste management strategy, policy or options for adoption on the farm. The hierarchy is from the most preferred (avoidance of waste generation) to the least preferred (disposal) waste management options. The waste management hierarchy can be applied to animal manure management as shown in **Table 6**.

4. Some principles associated with manure management

There are several principles which are associated with waste management [11] and by extension, manure management. It is important to take these principles into account when formulating manure management strategies and interventions. Some of the principles are as follows:

- Proximity principle: The principle of proximity indicates that as practicable as possible, wastes should be managed close to where they are produced.
- Self-sufficiency principle: The principle of self-sufficiency indicates that each country, and potentially each state, region and city, should manage its own wastes wherever possible. If applied to animal production facilities, this means farms should manage the wastes that they generate. However, this principle does not foreclose regional cooperation, which may be the most efficient and environmentally sound way of waste management.
- The polluter-pays principle: This principle indicates that those who cause or generate pollution should bear its cost. In this context, those who generate manure should bear the cost of managing it to prevent the potential risks to human health and the environment.
- Precautionary principle: This principle is applied according to the capabilities of the affected states. According to the principle of precaution, the absence of scientific certainty shall not be used as the reason for postponing cost-effective measures to prevent environment degradation, particularly where substantial threats of serious or irreversible damage exist [11].
- Sustainable development: The principle indicates that development activities geared towards meeting the needs of the present must not compromise the ability of the future generations to meet their own needs. Thus, manure should be handled and managed in such a way that will not negatively affect the environment.
- Principle of intergenerational equity: The principle of intergenerational equity indicates that waste should not be managed in such a way that will leave the responsibility for the problems to the subsequent generations.

5. Challenges associated with manure handling

Animal manure can be a challenge when produced in excess of requirements. Unsustainable manure management practices, which consist of various disposal approaches, are still prevalent in some places (**Table 7**). This is particularly the situation in some intensive animal operations. For example, costs associated with manure storage and disposal can contribute to unsustainable practices in handling manure. This is possible especially when the alternatives to sustainable management are considered much cheaper, in terms of financial requirement. However, the public health and economic costs in form of disease outbreaks, rejects of products, products recalls and regulatory fines and so on that could be associated with improper disposal of animal manure or manure contaminated foods and food products may far exceed whatever cost-savings are being targeted by the producers who adopt unsustainable manure

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Manure management method	Proportion of farms* (%)	Proportion of farms** (%)
Sold	—	20
Buried	—	5
Burnt	26	23.33
Recycled into crop production	—	14.17
Dumped in bushes or farms	37	—
Flushed in pits, streams and rivers	21	21.25
Others (combination of above practices)	16	16.25

*Source: [17].
**Source: [18].

Table 7. Prevalence of unsustainable manure management practices.

management practices. Manure disposal is the most unsustainable and by far the least desirable strategy in the hierarchy of management. Animal manure could be a valuable resource or a waste depending on how it is handled and managed.

Animal manure contains significant amounts of micro-organisms which make it a source of major risk to the public (**Table 8**). Risks of nutrients, organic material and pathogens contaminating water bodies and food products are common with increased manure spread [19]. Nutrient run-off into groundwater can occur from uncovered livestock facilities, from manure

Organism	Type of organism	Illness caused in humans	Route of infection
Escherichia coli	Bacteria	Bloody diarrhea, severe anemia, kidney failure or even death	Direct contact with feces and through water contaminated with feces
Campylobacter	Bacteria	Diarrhea and systemic illness	Fecal contaminated water
Salmonella	Bacteria	Diarrhea, fever, and abdominal cramp	Through fecal contaminated water or food
Leptospira	Bacteria	Leptospirosis with symptoms such as high fever, kidney or liver failure, meningitis, or even death	Directly through animal urine or soil containing animal urine contacting breaks in the eyes, skin, mouth or nose
Listeria	Bacteria	Listeriosis characterized by fever, chills, headache, upset stomach and vomiting, most likely to affect pregnant women and unborn babies	Manure contaminated food
Shigella	Bacteria	Bloody diarrhea	Direct contact with feces
Cryptosporidium	Parasite	Watery diarrhea, may be life-threatening to peoples with poor immune system	Soil, water, food, or surfaces contaminated with feces of infected animal
Hepatitis A	Virus	Viral liver disease causing mild to severe illness, flu-like symptom, diarrhea, fever, discomfort, decreased appetite, tiredness	Fecal, or by indirect contact through contaminated food and water
Rotavirus	Virus	Gastroenteritis. Symptoms include severe diarrhea, vomiting, fever, and dehydration	Contamination of hands, objects, food or water with infected feces

Organism	Type of organism	Illness caused in humans	Route of infection
Nipah virus	Virus	Severe illness in both animal and human. Asymptomatic infection to acute respiratory syndrome and fatal encephalitis	Eating food contaminated by feces of infected animal
Avian Influenza	Virus	Conjunctivitis, fever, cough, sore throat, muscle aches, pneumonia	Contact with contaminated droppings
Source: Adapted from [20].			

Table 8. Animal manure, potential pathogens and illnesses caused in humans.

applied to land, from pasture feeding and watering areas or from direct discharge into water bodies which causes water pollution.

Major consequences of manure pollution in water bodies include oxygen depletion due to increased biological oxygen demand and the resultant effect on sustainable fisheries, eutrophication and algae bloom, water taints and odor, nitrate poisoning in humans and animals and water acting as a carrier for several disease pathogens [21]. Gaseous emissions from manure facilities contribute to noxious odor, greenhouse effect and other potential health hazards. Apart from the direct discharge of manure or its constituents, water bodies can absorb airborne manure constituents. Substantial amounts of nutrients, particularly nitrogen, are lost during manure collection, storage and removal. Therefore, animal manure can be a contaminant for food, soil and water. Manure is also a cause of offensive odor. Therefore, manure management systems must integrate appropriate measures for odor control. Reducing the frequency, intensity, duration and offensiveness of the odor is the main goal of effective odor control.

6. Strategies for promoting sustainable manure management

6.1. Policy and legal frameworks for sustainable manure management

In view of the numerous challenges associated with manure handling, relevant policies, legislations, regulations, directives, codes, standards and guidelines have been enacted to promote its sustainable management. The responsibility of setting policies and/or regulations for manure management could rest with the federal, state, local or provincial government. A policy articulates the course of action or principles and associated guidelines adopted to guide decisions and achieve some national outcomes relating to particular issues. Policies should usually have long-term goals. A manure policy is supposed to outline rules, provide principles that guide actions and set roles and responsibilities of waste generators and the public authorities. It also reflects values and beliefs as well as the intention to take action. Legislations and regulations are usually set to give effect to the manure management policy. Guidelines, standards, codes and procedures may also be associated with a policy. Policies may include mandatory or voluntary compliance.

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Manure management policies could be a stand-alone policy or a part of another. National Agricultural Policy, Environmental Policy, Climate Change Policy, Energy Policy, Renewable Energy Policy, Livestock Development Policy, Poultry Development Policy, Food Safety Policy, Water Policy, Integrated Waste Management Policy and so on do address some aspects of manure management. A challenge with the policies earlier mentioned in relation to manure issues is that they may not be comprehensive as desirable or adequately cover every important aspect of manure management. This is the situation in several countries. Dedicated manure management policies and legislations may address the gaps associated with the other policies in relation to manure issues. The Integrated Livestock Manure Management Policy of Bangladesh is an example of a stand-alone manure policy [20]. Manure management hierarchy can guide the formulation of manure management policy objectives. To make the manure management policies effective, goals and targets can be set over various time scales. It is essential to involve the stakeholders in the processes of formulating the policies and strategies. The stakeholders should also be adequately sensitized as per their roles and responsibilities relating to sound manure management.

Policy incoherence and weak enforcement due to the lack of coordination among relevant ministries are other major challenges associated with manure policies in several countries [22]. It suffices to note that policy implementation is challenging without accompanying it with enforcement and compliance. Legislations can also contribute to increased litigation associated with manure management. Ref. [23] noted adding incentives in the form of subsidies to mandatory requirements could help to fast-track and enlarge the adoption of sustainable manure management practices such as anaerobic digestion of animal manure.

Dutch manure policy has been reported to have the following impacts: a decreased fraction of phosphate and nitrogen from the synthetic fertilizer and reduced nutrient dispersion in the environment. The success of the policy implementation has been attributed to strict application of standards for agricultural production, more efficient production per animal, low emission from stored and applied manure, manure processing, transportation and export.

6.2. Manure management practices

6.2.1. Nutritional strategies for reducing the environmental impact of animal agriculture

Feeding strategies can also be used to reduce livestock manure yield and potential emissions from manure management. Ref. [24] reported that chickens fed low protein diets had lower manure output and reduced nitrogen output intensity compared to those on higher protein regimes. The studies also found that amino acid supplementation, enzyme supplementation and manure treatments with various types of alum resulted in additional reduction in nitrogen excretion in chickens [24–27]. The implication of the finding is that lower manure and nutrient output reduces their potential environmental impacts.

6.2.2. Manure treatment

Manure treatment can be physical, biological or chemical. The objectives of manure treatment include reduction of manure volume, improvement of its applicability and/or increase in fertilizer value. Forms of treatment include dehydration, solid separation, anaerobic and aerobic lagoons, nutrient fortification, pelletizing, composting, refining and methane digester [22, 28].

Treatment with alum: Alum (aluminum sulphate), sodium bisulphate and mineral or organic acids are some of the materials that could be used for litter or manure amendments for N and NH_3 as well as other benefits [29]. Amendments of manure could be utilized to further control mineral volatilization and other forms of releases from animal manure. Alum, also referred to as filter alum ($Al_2(SO_4)_2$), is used as a flocculating agent in the purification of drinking water and waste-water treatment. Use of alum is an effective method of reducing nitrogen loss due to ammonia volatilization [30]. Use of alum in chicken manure amendment would lead to decreases in animal-house ammonia level, reduction in energy usage, improvement in animal performance, precipitation of soluble phosphorus, reduction of phosphorus and heavy-metals run-off and imposition of drying effect that reduces litter moisture. Manure treated with 1.5% alum inclusion had higher nitrogen content than untreated manure during a week of storage [27]. Nitrogen concentration in alum-treated manure tends to be elevated compared to normal manure. Elevated fecal nitrogen in stored alum-treated manure was attributed to a lower magnitude of nitrogen loss in treated compared with untreated manure and enhances its fertilizer value.

Composting: This is a natural process of aerobic decomposition or fermentation of manure by micro-organisms. Compost is rich in organic matter and has the ability to improve soil health. Compost can be made either through heap/pile or through pit method. Some of the benefits of compost in the soil include improved fertility, water-holding capacity, bulk density and biological properties [31]. A lower number of viable weed seeds in composted manure contributes to the reduction in the use of herbicides or tillage requirements for weed control [32]. Composting could be effective in killing some pathogens in manure. It also leads to up to 50–60% of reduction in the volume and density of manure thereby making its transportation more energy efficient than that of non-composted manure [33].

Anaerobic digestion: Anaerobic digestion of manure is the processing of manure to produce energy, mainly biogas. Anaerobic digestion of manure can be made more efficient through the use of co-products such as water hyacinth, corn silage and so on. Methane yield differs from various animal manure types. Rice straw (550–620 m^3 biogas/tonne DM), maize straw (400–1000 m^3 biogas/tonne DM), vegetable wastes (400 m^3 biogas/tonne DM) and kitchen wastes (400–1000 m^3 biogas/tonne DM) yield relatively more biogas than animal manure with biogas yield of 200–300, 250–500, 310 and 300–400 m^3 biogas/tonne DM for cattle, pig, poultry and sheep manure, respectively [34]. Biogas from manure digester can be used for cooking instead of the direct burning of biomass. It can also be used to power the generator for electricity. The composition of biogas produced for bio-digester is 50–70% methane, 30–45% carbon dioxide, 0–3% nitrogen, 0–3% oxygen, 0–3% hydrogen [22] and the heating value of the gas ranges from 18 to 25 MJ/m^3 [35, 36]. Whereas the biogas market may currently be underdeveloped in several countries of the world, it holds great potentials if rightly channeled to meet some of the national energy targets. The digestate from manure digestion is valuable as a fertilizer and should be used as such. However, this may require additional technologies and costs because of the high moisture content [37]. Sales of bio-energy and compost/manure substrate from biogestion can be economically viable while at the same time contribute to a safe and sane environment [38].

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6.3. Strategies for odor control from livestock manure

Manure is one of the most common and main sources of odor in a livestock operation. Ref. [28] provided the following guidance on strategies for odor control from livestock manure:

- Plan, design, construct and manage livestock operations in a way that minimizes the impact of odor on neighbors. This will require reducing the formation of odor-forming gases and reducing their release into the atmosphere.
- The location of livestock operations, particularly outside lot systems, should maintain a safe distance from residents and other odor-sensitive land use. This is because odors may be generated from these systems even with good facilities design and management practices.
- As much as possible, manure storage facilities should not be located close to residential areas.
- Solid manure from farm animals can be stacked on a temporary basis outside the livestock building. Farmstead stockpiled manure should be on a hard surface, preventing direct contact with the soil. Where they are in direct contact with the soil, they should be temporary and removed from time to time. Such grounds should be left vegetated for at least 3 years to allow enough time for the nutrients to be taken up by plants. Stockpiles could also be covered with straw, wood chips and other materials and/or treated with additives such as lime to help reduce odors and pests. Field stockpiles must be temporary and should not be in an area that allows nutrient run-off.
- Manure storage facilities are temporary measures to hold manure-pending soil application. Therefore, where it is economically and technically feasible, covered manure storage facility should be used. This is because uncovered manure storage facilities are more prone to release odor into the atmosphere.
- Manure should be incorporated into the soil almost immediately after application where feasible.
- Odor from manure can also be reduced through treatment. For example, composting manure reduces odor [39].

7. Future of manure management

Manure management is an integral part of the waste management system. Therefore, current trends shaping waste management policies and practices will dictate the direction of future shifts in manure management. Several authors have identified some trends and those expected to influence future animal manure management systems, policies and practices. In a bid to reduce the quantity of wastes generated in the production, multiple industries are now leaning towards sustainable innovations and processes in the sourcing and production of items; the use of renewable resources and environmentally friendly raw materials is being favored, and products and materials that cannot be recycled are being eliminated from the production.

Waste management policies and regulations are also improving speedily globally. The rate of recycling solid wastes is increasing fast in some countries around the world [40].

There is so much going around the world in relation to manure management. The current trends in manure management are expected to further intensify in the nearest future. The future of manure management is expected to be shaped by a number of factors, one of which is regulatory compliance. Compliance with existing international, regional and national policies and laws and regulations on manure management will be a major determinant of future manure management practices. For example in Denmark, it has been noted that the European Union legal framework on manure will influence future actions and priorities in manure management [41].

The factors that will influence the general trends and development in animal agriculture will exert both direct and indirect influence on future manure management practices. In the future, several countries will be seen putting in place relevant laws and taking actions to promote sustainable manure management practices. This is because as animal production increases, measures to reduce and recycle manure are expected to increase as well. For example, the crises associated with the mobile nature of cattle production in some parts of the world have necessitated serious consideration of a shift towards encouraging sedentary production in many countries. The current cattle population needs to develop larger productive breeds, and increased intensification may result in the accumulation of greater volume of manure accumulated in some locations. This is because intensification increases the potential of manure accumulation in the producing areas [42]. Thus, policies promoting intensification of cattle and other livestock must be accompanied with relevant regulations on manure management in those places. This will require strong institutions, relevant infrastructure and sustainable partnerships to be in place to combat unsustainable manure management, particularly in places which currently have a weak regulatory and institutional framework for manure management. Lessons from other nations with successful manure management trends and history will be valuable for countries where manure management is currently emerging.

Trade is another potential driver of future manure management practices. On the one hand, food safety and global health concerns in traded food commodities will play a major role in shaping future manure management practices as it affects international and cross-border trades. On the other hand, increasing opportunities to trade high-quality improved manure products which could be used for several beneficial purposes will stimulate actions.

Availability of cheap, efficient and easy-to-adopt/adapt manure management technologies is expected to play a key role in stimulating actions. Unless environmentally and economically sustainable management technologies are employed, environmental pollution becomes inevitable [43]. Technological innovations are expected to contribute to significant improvement in the efficiency and effectiveness of waste management systems. Innovations in reduction, reuse and recycling of manure are therefore expected to increase in the nearest future. With increased development and dissemination of adaptable technologies, it would become more convenient for industry actors to adopt sustainable manure management practices in the nearest future. For example, innovations in manure nutrient fortification, reducing the variability of manure components, nutrient extraction and purification will remove some of the

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limitations in the use of manure as a fertilizer. Sustainable manure management can be a veritable income spinner and may also constitute significant savings on farm expenditure or cost of trading. The prospect of some forms of economic benefits from sustainable manure management may promote appropriate actions.

Development, professionalization and popularization of the manure management career will also stimulate positive actions in future manure management practices. Innovations and research in the area of manure management will go a long way in promoting this field of specialization. In view of the need for farmers to comply with more stringent manure management requirements, they may need to employ the services of skilled professionals with specialized knowledge in manure handling. They would partner with the farmers to enable them to better cope with the challenges of managing manure sustainably. This will mean more people will work in this and other areas of solid waste management. There will also be the need to add new competencies due to the need to perform a wide range of environmental-related management activities. The emergence of small businesses that specialize in manure management should be encouraged and promoted to service the industry.

The drive towards ensuring a safe environment in the future will also promote the practice of sustainable manure management. Animal manure disposal is the least preferred option for manure management. The shifting preference from disposal to more sustainable options in manure management hierarchy is expected to continue. Therefore, increased awareness of the advantages of sustainable practices and better alternatives to disposal is expected to play a crucial role in driving future actions in manure management. There are several sustainable development goals that could directly or indirectly influence positive actions in future manure management. These include SDG 1, 2, 3, 6, 7, 8, 10, 11, 12, 13, 14 and 15 [20].

Pressure from sustainable manure management groups and movements is expected to increase and stimulate appropriate actions to promote responsible manure management practices around the globe. The operations of these advocates are expected to produce an increasing number of sustainable manure management champions. Hence the number of initiatives to address manure management-related issues is expected to increase significantly.

8. Conclusion

The importance of sustainable animal manure management cannot be over-emphasized. However, generated on the farm, the impact of manure transcends its source of production. Manure contamination has been implicated in several public health epidemics around the world. Sustainable management of manure requires a multi-pronged approach. These approaches include nutritional strategies, policy and legal framework as well as physical, biological and chemical manure treatment. Effective manure policy, legislation and regulations will promote efficient and sustainable manure management practices, especially, with adequate enforcement and compliance. Manure management strategies adopted should efficiently mitigate the negative impact of manure on the environment and the general public. Several benefits are derivable from sustainable manure management.

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