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REVIEW

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Benefits, concerns and prospects of using goat manure in sub-Saharan Africa

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Abstract

Livestock production has undergone an industrial revolution over the past few decades. This has resulted in the enormous generation of livestock manure, particularly in agro-pastoral systems. Agricultural productivity in these systems largely depends on livestock manure. However, some of these communities are struggling with goat manure disposal. In addition, livestock manure requires proper treatment before application to agricultural land, because it contains toxic heavy metals and pathogenic microorganisms. The review aimed to demonstrate that poor manure management has environmental consequences; thus, interventions that will promote local community livelihood benefits from animal wastes are germane. In many other communities in sub-Saharan Africa (SSA), horticulture or crop production is minimal, due to erratic rainfall hence, most of the manure lies idle in abandoned kraal pens or is heaped outside the pens with no designed plan. Manure should be viewed as a resource, rather than a waste product. The environmental consequences associated with such manure management are not known and should be probed further. Deliberate efforts to explore the land and environmental risks associated with the non-use of livestock manure are germane to promoting environmental stewardship. The use of manure as feedstock for anaerobic digesters offers the greatest potential for sustainable management in SSA.

Keywords Environmental pollution, Ecosystem, Decomposition, Rural livelihoods, Small ruminants

Introduction

Small ruminant production is predicted as the most viable economic activity for drought-prone areas in sub-Saharan Africa (Devendra 2015; Marandure et al. 2020; Phetogo et al. 2020; Washaya et al. 2019; Thornton 2010). In such environments, the demand for livestock products has been on the rise (Tadesse 2018; Scholtz et al. 2011), due to the growing human population, changes in income and food preferences. As reported by Homann et al. (2007), the role of livestock, particularly goats, has rapidly changed in rural communities. They are increasingly used to augment household cash income and promote food security in drought-prone areas (Homann et al. 2007). These characteristics are important because goats require low maintenance requirements (Nizar et al. 2014), are relatively inexpensive to rear, require less dry matter intake and space, can utilize ragged land that is inappropriate for crop production and are prolific (Msalya et al. 2017). In agreement, Dube et al. (2017) hypothesized that the goat population in Zimbabwe is increasing particularly in Matabeleland South. Unfortunately, the high number of goats per household contributes to volumes of unused manure. In general, rural communities do not use goat manure for anything; it is not preferred compared to cattle, pig or poultry manures (Wuta and Nyamugata 2012) in horticulture projects; and hence, there is a rampant accumulation. Under intensive production systems, large amounts of livestock manures are stored in piles or lagoons, managed to decrease nutrient and pathogen concentrations and processed into organic fertilizer

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(Kumar et al. 2013). This practice is not feasible in some parts of Zimbabwe including Beitbridge, because very few crops or horticulture production is possible, due to arid climatic conditions. Therefore, heaps of decomposing manure are common, posing an environmental threat to inhabitants. The problem of accumulating small ruminant manure has also been reported in Kenya (Antony et al. 2013; Jagisso et al. 2019) and Australia (Arnaudin 2012), and burning or use of beetles has been the most valuable urgent option for these nations. We, however, do not recommend any of these methods because manure can be used for many other things like the production of biogas, liquid fertilizer or even selling to generate household income. Under pastoral systems, manure can simply be spread over the rangeland, thus improving both soil and biomass characteristics. This may not be feasible in most communities within SSA, because animals are housed at night; therefore, manure accumulation happens within kraals. Nonetheless, other means of disposing of manure have been identified in this review, which will benefit these resource-challenged farmers. The environmental impacts of improper disposal of manure have not been researched in most SSA counties, although its contribution to environmental pollution is evident. To this end, little is known about the productivity, composition, decomposition, biogas potential and environmental impacts of goat manure. Therefore, the review aimed to highlight the potential environmental consequences of improper disposal of goat manure in SSA and promote possible solutions to avert the scourge.

Approach

A pilot survey revealed decomposing heaps of goat manure in the Beitbridge area. Therefore, recently published evidence was reviewed, focusing on manure management to promote interventions that can be actuated to mitigate environmental pollution across agro-pastoral systems in SSA. Published work, in English, focusing on current trends, that: (a) addresses the availability, benefits and quality of goat manure (b) nutrient content and use of goat manure as a fertilizer (c) decomposition of manure and biogas production (d) environmental impacts, (e) policy regulation of manure and (f) are relevant to livelihoods and income generation in sub-Saharan Africa was analysed. Relevant publications were identified through keyword searches with Google, Google Scholar, Web of Science, Springer Link, ScienceDirect and ResearchGate, and more than 150 publications were reviewed. Priority was given to publications that suit at least two of the search factors.

Availability and quality of goat manure

While in other countries manure is available, some countries show very low quantities of manure for either agricultural or energy uses; for example, in Ghana, livestock manure is only available in the small-scale sector and its utilization for large-scale biogas systems can be challenging (Ulrike et al. 2014). A similar report was given by Antony et al. (2013) in Kenya, where manure is abundant in drier areas with no cropping activity. A possible solution to excess manure accumulation in, for example, the Beitbridge area in Zimbabwe would be to exchange manure for crop residuals to feed livestock, this was done in Northwest Nigeria and the results were phenomenal (Antony et al. 2013). Table 1 shows manure production from various farm animals.

The manure extraction from a goat which has a body weight of 20–40 kg is approximately 0.32–0.625 kg per day, equivalent to about 0.3 tons per year (Erdogdu et al. 2019). In a study by Ansah et al. (2019) and Hanafiah et al. (2017), goat manure weighed 178.67–216.17 g/day and 0.7 kg/day respectively. On average, farmers who own > 45 goats per household can produce approximately 21.3 kg manure per day and 7760.8 kg manure per year. Such volumes of manure would require a codified manure management system, without which environmental pollution ensues. In spite of the challenges so far identified, goat manure possesses a higher N concentration

Table 1 Manure production (% live weight per day) from different livestock in sub-Saharan Africa

Species	Wet weight	Dry weight	Average weight of animal (kg per head)	Manure production each day (kg day^{-1} of dry weight per head)
Pork pigs	5.1	1.275	45	0.57
Laying hens	6.6	1.65	1.5	0.02
Feedlot sheep	3.6	0.9	25	0.23
Goat	-	-	-	1.5
Feedlot beef	4.6	1.15	217	2.50
Dairy cattle	9.4	2.35	356	8.36

Source: Orskov et al. (2014)

compared to cattle manure (Zhu et al. 2020a), because small ruminants actively select plants of higher nutritional value to constitute their daily food. Animal excreta has high concentrations of easily decomposable C and N compounds compared to plant litter; therefore, it provides readily accessible nutrients to soil microorganisms leading to accelerated decomposition rates (Zhu et al. 2020a). Thus, biomass decomposition becomes energetically favourable with animal than plant-based waste.

Nutrient content of goat manure

Goat manure has a higher content of N and phosphoric acid than that of cows, and the urine is rich in N and potassium (K) (Ansah et al. 2019). Previous research (Saha et al. 2008) has shown that goat manure contains low C: N ratio below the critical level of 20 (Ansah et al. 2019; Wuta and Nyamugata 2012; Prieto et al. 2019; Zechmeister-Boltenstern et al. 2015; Zhu et al. 2020a) and is important in nitrogen mineralization and stabilization of farming systems. Besides the provision of organic matter, goat manure has the potential to provide adequate N, P and K nutrients required by most crops (Wuta and Nyamugata 2012; Msalya et al. 2017; Orgiazzi and Briones 2021). Sub-Saharan soils are predominantly phosphate (P) deficient; the use of organic manure as soil amendments for P-deficient soils is a welcome recommendation. The nutritional composition of animal manures is presented in Table 2. Given the information (Table 2), the preferred use of cattle manure by farmers in cropping lands is unjustified, and we believe farmers need to be educated on this fact. The only justification would be quantity-related, as goats naturally would produce approximately 300 g manure/day compared to 25 kg/day from cattle (Msalya et al. 2017). The storage of manure beyond 6 months systematically reduces its nutritive potential for crop production; Lim et al. (2023) reported that the N level significantly drops due to ammonia volatilization leading to nutrient imbalance, particularly the N to P ratio. To this end, we recommend that farmers compost goat manure with other crop residues to increase its value (Lim et al. 2023). However, this process might increase the carbon footprint of manure as more carbon is emitted as CO_2 rather than CH_4 under anaerobic conditions. At the present moment, both endpoints can be explored to improve soil characteristics as well as abet and avert environmental pollution.

Soil fertility

Without any doubt, low soil fertility is the most important constraint limiting crop productivity in SSA (Gicheru 2012; Fischer and Qaim 2012; Antony et al. 2013; Ansah et al. 2019), and manures that are rich in organic matter (OM) are used in soil amendments (Orgiazzi and Briones 2021). Manure stimulates the multiplication of microorganisms that are antagonistic to plant parasitic nematodes (Ansah et al. 2019), thereby promoting a disease-free crop. The nutrient composition of manure, particularly the carbon-to-nitrogen ratio (C:N) is critical for crop production. Under intensive agriculture, the organic matter content is often < 2% and such soils are not optimum for crop production (Batubara et al. 2021). We believe the addition of manure can boost the OM content to acceptable levels even in pastoral and extensive production systems because organic manures improve plant root rizoster conditions (Mbatha et al. 2021), thus enhancing the assimilation of nutrients from the soil. The addition of manure increased soil organic carbon (SOC) stocks by 35.4% in agricultural soils (Gross and Glaser 2021). Animal manure plays a vital role in blocking P sorption sites in the soils (Gichangi et al. 2010), thereby improving soil-available P. In addition, manure contributes to the improvement of the physical properties of soil, such as soil structure, water-holding capacity and water infiltration. These soil properties are critical in arid and drought-prone areas, where crop failure is common, typical of Beitbridge. In developing countries,

Table 2 Nutrient concentration of cattle and goat manure from kraals and compost heap

Species	Manure Type	Nutrient %					Reference
		N	P	K	OC	C:N	
Cattle	Fresh	1.68	0.28	0.54	28.0	20	Wuta and Nyamugata 2012
	Decomposed	1.05	0.26	0.42	18.7	18	
Goat	Fresh	2.57	0.36	0.77	26.2	12	
	Decomposed	2.23	1.24	3.69	19.1	11	
Pig		0.68	0.63	0.49	-	-	Ndambi et al. 2019
Broiler		3.00	1.90	1.71	14.9 [1]	9 [1]	
Layer		2.36	1.70	1.10	14.7 [1]	7.8 [1]	

N, nitrogen; *P*, phosphate; *K*, potassium; *OC*, organic carbon; *C:N*, carbon: nitrogen ratio (Maerere et al. 2009) organic fertilizers are mainly produced from agricultural wastes such as cow manure or municipal solid wastes (Oyesola and Obabire 2011), poultry and goat manures (Adhikari et al. 2016), and bio-slurry (digestate) is the by-product of biogas production (Ramos 2017), therefore improving soil physical properties. In agreement, high crop yields (Adhikari et al. 2016) and a significant reduction in soil erosion (Angin and Yaganoglu 2011) have resulted from the use of organic fertilizers. Fresh manure is acidic (Ansah et al. 2019), hence the recommendation to use composted or decomposed manure. Previous studies have demonstrated that manure decomposition is regulated by its main structural components like cellulose (Zhou et al. 2019), the primary substrate for glucan depolymerization at later stages of decomposition. This only happens after more labile C compounds (sugars and starch) have been depleted (Zhu et al. 2020a). Nonetheless, cellulose decomposition can be very fast, because goat manure is already rich in cellulolytic bacteria from the rumen (Zhu et al. 2020a). According to the theory of ecological stoichiometry (Zechmeister-Boltenstern et al. 2015), microbial decomposers build their biomass when they have access to both C and N in a rather narrow ratio. This theory supports the idea that the mineralization of C and its subsequent release as CO_2 is accompanied by the retention of mineralized N. On the other hand, higher initial N concentrations favour N mineralization (Kuypers et al. 2018), thus averting problems of nutrient loading and pollution. Furthermore, manure plays a major role in C and N cycling in grassland ecosystems (Orgiazzi and Briones 2021). The use of manure to improve crop yields has been demonstrated in many SSA countries (Table 3); however, very few have used goat manure. Again, this proves heavy reliance on poultry or cattle manure, which is typical in SSA. According to Tully et al. (2017), African soils are "tired" degraded, severely leached and nutrient mined by crops AGRA (2019), and continued imbalanced use of fertilizers will lead to serious environmental impacts. Indeed, the use of inorganic fertilizers is the main cause of environmental degradation in SSA (Jama et al. 2017), manuring these soils can be the only eco-friendly way to improve both the physical and chemical properties of these soils. Ndung'u et al. (2021) demonstrated that the long-term application of goat manure increases maize yield and soil C sequestration potential. The pyrolysis of goat manure to biochar has been reported to improve soil quality as well as other agronomic benefits (Lim et al. 2023).

Use of goat manure as a fertilizer

The use of inorganic fertilizers acidifies African soils (AGRA 2019); this has ripple effects on biodiversity and biomass production, which further disturb soil physicochemical properties. The cost of inorganic or organic fertilizers is still high for rural farmers (Antony et al. 2013); manure can be the only solution to this persistent problem. The use of organic waste as fertilizers is on the rise globally and is attracting the attention of the food production sector (Maffei et al. 2016). This serves as an alternative means of disposing organic agricultural wastes, thereby reducing pollution (Sun et al. 2012). Goat manure performed better than cattle manure in Tanzania (Maerere et al. 2009) and improved both plant growth and soil chemical properties. Ndung'u et al. (2021) reported that goat manure contained adequate amounts of nutrients to meet maize plant requirements for optimal growth. In China (Du et al. 2020), manure application increased crop yields by approximately 8.5–14.2 Mg ha^{-1}. This is achieved through higher SOC and total nitrogen contents as well as increased microbial enzymatic activities. Evidence from Ethiopia and Malawi (Ndambi et al. 2019) where lead farmers were chosen to demonstrate the effects of various forms of manure-based fertilizers can be transcribed to other SSA countries to appraise the impacts of manure-integrated crop production systems. It is regrettable that in most SSA countries, manure is not often applied to agricultural soils, but is left to accumulate before being washed into water bodies without any treatment (Teenstra et al. 2014), polluting these reservoirs. Goat manure potentially increases the aromatic

Table 3 Comparison of yield improvement of various crops due to manure application in different countries in SSA

Country	Crop cultivated	Manure type	Application rate (t/ha)	Crop yield increase (T/ha)	Reference
Kenya	Maize	Goat	60 kgN/ha	4.1	Ndung'u et al. (2021)
Zimbabwe	Soybean	Cattle	14	1.18 vs 0.57	Zingore and Giller (2012)
Nigeria	Watermelon	Poultry	5	422.8 vs 245.2	Enujeke (2013)
Malawi	Cassava	Cattle	5	27.61 vs 21.90	Mathias and Kabambe (2015)
Zambia	Cassava	Poultry	4.2	28.5vs 19.8	Biratu et al. (2018)
Zimbabwe	Tomatoes	Goat	10	2.7 times more than control	Chipomho et al. (2018)

Source: Ndambi et al. (2019)

carbon content of soils; this is a remedy for poor soil organic carbon which is domiciled in SSA soils, again the continued use of inorganic fertilizers decreases the aromatic C, underscoring the potentially adverse effects of inorganic fertilizers. In addition, algae treatment of goat manure to produce a slow-release fertilizer can be tried in nations where accumulation of manure is observed.

Use of goat manure as a feedstock for biogas production

There is a persistently high demand for wood fuel in rural SSA households, which inadvertently threatens forest resources, consequently increasing its carbon footprint (Arthur et al. 2020). The devastating effects of deforestation in SSA are ignored even in the Twenty-first century where global warming and climate change are subjects of our era. Regardless, developing economies still rely on firewood to power their rural energy requirements, a situation that is self-destructive and environmentally unsustainable (Gemechu 2020). In this regard, we proffer the use of biogas as a solution to household energy requirements, which also comes with a plethora of other benefits including biofertilizers. For small-scale farmers in Asia and Africa, the feedstock for biogas production is mainly excreta from livestock (Orskov et al. 2014). Animal manure is an ideal feedstock for biogas production because of its high moisture and volatile solids (VS) content, the buffering capacity and its variety of microbial strains (Pilloni and Abu Hamed 2021). However, animal manure lacks carbohydrates thus can slow digestion and can generate voluminous ammonia concentrations, which are unfavourable for methanogens. Biogas technology is still in its infancy in Africa, although recent initiatives have resulted in the accelerated uptake and understanding of the technology in various African countries. Digesters have been installed in several African countries and National biogas programmes have been implemented in Kenya, Uganda, Ethiopia, Tanzania, Rwanda, Cameroon, Burkina Faso and Benin (Kaifa and Parawira 2019). As reported by Kaifa and Parawira (2019), most biogas plants are oversized in relation to animal manure or any other feedstock resources available to run the digester to produce enough biogas. Hence, there is a need for research and consultations on the size of the digesters for households before construction. The projected potential for methane production from livestock manure has been shown to increase (Arthur et al. 2020); however, goat manure is among the top sources for biogas production with 19.9 compared to 78.2, 60, 13.8 and 11.4×10^6 m^3 for chicken, cattle, sheep and pigs, respectively. Excess manure can undergo thermochemical processing by combustion, pyrolysis and gasification, which leads to various products (Lim et al. 2023). However, most of these technologies are non-existent in SSA at the present moment, save for biochar production and its use in soil amelioration (Schmidt et al. 2021; Kaifa and Parawira 2019; Orskov et al. 2014) or animal nutrition. Table 4 shows the biogas production comparisons from manure among different farm animals. Evidence so far indicates that goats contribute less manure methane compared to cows and chickens (Hidayat et al. 2021). In light of these factors, biogas production is a preferred manure disposal method in SSA. Biogas consists of 45–70% methane gas, 25–40% carbon dioxide, < 10 ppm hydrogen sulphide, < 3 ppm nitrogen and < 1 ppm hydrogen (Hanafiah et al. 2017), and of these components, methane makes biogas flammable (Hidayat et al. 2021). While there are negative connotations associated with methane production, biogas is an eco-friendly use of animal waste products.

Table 4 Biogas production from different livestock in sub-Saharan Africa

Type of feedstock	Volatile solids per unit dry solids (kg kg^{-1})	Moisture content of fresh waste (dm^3 kg^{-1})	Biogas production per unit weight of volatile solids (dm^3 kg^{-1})	Total fresh waste produced per head (kg day^{-1})	Biogas production per unit weight of fresh waste (dm^3 kg^{-1})	Biogas production per head (dm^3 d^{-1})
Pork pigs	0.856	0.75	380	2.30	81	187
Laying hens	0.85	0.75	130	0.10	27	3
Feedlot sheep	0.85	0.75	170	0.90	36	33
[a]Goat	nd	18–25%	nd	nd	nd	0.3–0.4[b]
Cow (Sudan)	0.85	0.75	150	9.98	32	318
Feedlot beef cattle	0.85	0.75	470	16.56	100	1656
Dairy cattle	0.85	0.75	470	28.00	100	2800
Beef cattle	0.85	0.75	470	22.50	100	2250

Source: Orskov et al. (2014)

[a] Arthur et al. (2020)

[b] Nm^3/kg dry matter

Excess manure can also be algae treated, an advanced technology, to generate bioenergy (Lim et al. 2023), and this type of energy is preferred over anaerobic digesters. The opportunity cost associated with this technology is self-promoting.

Livelihoods and income generation

The sale of manure is a growing business in SSA, for example in Kenya a greater demand for small ruminant manure has been recorded by local farmers (Antony et al. 2013). The same authors also reported that small ruminant manure was preferred over cattle manure and such an endeavour would inevitably improve livelihoods through income generation in communities where manure is deemed valueless. In their study (Antony et al. 2013), individual traders and brokers bought manure from farmers and sold it to urban dwellers, and the revenue generated was unbelievable. No studies are comparing different manures, including goat manure, at the same site. However, from the results in Table 5, it is evident that goat manure significantly boosts revenue for small-scale farmers; hence, we proffer the use of goat manure in horticulture and other crop production entities for household income generation.

Although it has not been confirmed yet, entrepreneurs are developing markets for fibre found in manure (Lim et al. 2023). Farmers can also compost the excess manure or vermicomposting. Vermicomposting produces new worms and worm castings that are very high-value organic fertilizers (Taiwo and Otoo 2013). In this way, generates household income from both live worms and castings (worm manure). In most SSA rural communities, opportunities to develop irrigated horticulture gardens would promote the use of manure; thus, farmers realize income from increased productivity. Regardless of the current situation, manure marketing would promote increased household income, as well as reduce the impacts of manure on the environment. In developed countries, goat manure is pyrolysed slowly to produce bio-char, or fast to produce bio-oil (Erdogdu et al. 2019), and farmers can also benefit from the sale of goat manure; this would boost their household income (Msalya et al. 2017). We advocate that farmers develop miniature industrial plants for either bio-char or bio-oil production as a means to ameliorate poverty. The net earnings for community-based digesters are insufficient to pay back the investment and effort (Lim et al. 2023); this supports the idea for disadoption; therefore, we recommend government-owned and managed community

Table 5 The economics (USD) feasibility of using goat manure fertilizer in crop production

Crop		**Dosage of goat manure**			**Reference**
		0 ton/ha	**5 ton/ha**	**7.5ton/ha**	**Karyanto et al. (2010)**
Green Bean	Total production cost per ha	180. 28	214.10	227.63	
	Total revenue	124.81	238.96	307.46	
	Benefit (revenue – cost)	−55.47	24.86	79.82	
	Revenue cost ratio R/C	0.69	1.12	1.35	
Cherry tomato	Total Production cost per ha	182.38	216.20	229.73	
	Total revenue	104.52	357.18	416.23	
	Benefit (revenue – cost)	−77.86	140.98	186.50	
	Revenue cost ratio R/C	0.57	1.65	1.81	
Purple-egg crop		1.5 kg per hill			Ferichani (2013)
	Total production cost per ha	1.25			
	Total revenue	41.6			
	Benefit–cost ratio B/C	33.28			
Green-egg crop					
	Total production cost per ha	1.25			
	Total revenue	54.4			
	Benefit–cost ratio B/C	43.52			
Tomato	Total production cost per ha	1.25			
	Total revenue	50.0			
	Benefit–cost ratio B/C	40.0			
Chilli	Total production cost per ha	1.25			
	Total revenue	58.8			
	Benefit–cost ratio B/C	47.04			

biodigesters where farmers only supply the manure but benefit energy. Nevertheless, community digesters can safeguard farmers against uncertainty in prices and revenue streams (Sharara et al. 2020), provide an opportunity to better meet waste-disposal needs and prevent nutrient pollution in surrounding ecosystems.

Environmental impacts

Goat and sheep manure is largely unused resources in developing countries (Sanchez and Wilkie 2017), yet substantial industrial growths have been recorded over the past decades, and their contribution to environmental pollution warrants further study. There is mounting pressure to regulate livestock operations to reduce environmental pollution. In developing countries, there are no jurisdictions to prevent residential development in agricultural areas, posing a health threat to human beings (Erdogdu et al. 2019). In the modern era, the viability of the livestock industry is largely dependent on environmental sustainability. Unfortunately, and more often than not, the protection of the environment is not a major concern for the livestock industry. It is generally known that manure mismanagement is the fourth leading source of nitrous oxide emissions and the fifth leading source of methane emissions (Orangun et al. 2021). Approximately 78% of the N from livestock excreta is lost to the environment (Du et al. 2020), and this has ripple effects on the environment. Of all studied animals, goat manure contributed less Cu, Ni and Zn to the environment (Table 6). Animal faecal matter leads to water and odour pollution because of hydrogen sulphide and ammonia gas released during decomposition (Hanafiah et al. 2017). Two main odours have been identified: a pungent smell (ammonia) and a rotten egg smell (hydrogen sulphide) (Gbotosho and Burt 2013). It is unfortunate that among the animal manures, goat manure has low moisture and high C:N values, a good recipe for higher GHGs and unpleasant odours (Kaur and Kommalapati 2021). In light of these characteristics, we proffer that goat manure which is lying idle in many parts of Zimbabwe utilized for biogas production. This would lower its environmental impact as well as boost energy supplies.

It is factual that the volatilization of ammonia caused by the uncovering of heaped manure is a health hazard (Gbotosho and Burt 2013). Long-term exposure to ammonia has been reported to cause chronic ailments in human beings (Gbotosho and Burt 2013). Nitrates in drinking water create a human health hazard and reduce the performance of livestock. Although beneficial, the application of livestock manure to agricultural land may result in serious environmental problems (Kumar et al. 2013) including toxicity of manure to plants, and the accumulation of trace metals in plants and water bodies.

Nonetheless, kraal manure that is periodically moved can result in beneficial elevated nutrient patches that benefit both crops and pastures. Animal faeces can harbour human pathogenic microorganisms, therefore increasing health risks to both humans and animals (Kumar et al. 2013). The application of manure causes sodium accumulation in soils, consequently leading to soil salinity (Carter and Kim 2013; Gbotosho and Burt 2013). Manure can be managed effectively to reduce adverse health and

Table 6 Heavy metal contents and their sources in various countries (mg kg^{-1})

Country	Source	Heavy metal content (mg/kg)				
		Cd	**Cu**	**Ni**	**Pb**	**Zn**
Korea	Composted cow manure	0.5	10	4	21	21
	Composted sine manure	1.1	466	11	38.2	566
Spain	Composted cattle manure	0.8	35	-	9.8	142
	Poultry		14	37	18	94
UK	Beef cattle farmyard	0.13	16.4	2.0	1.95	81
	Dairy cattle farmyard	0.38	97.5	3.7	3.61	153
	Pig farmyard	0.37	374	7.5	2.94	575
	Layer manure	1.06	64.8	7.1	8.37	459
Canada	Poultry	0.48	54.3	7	2.3	550
Italy	Farmyard	6.0	66	14	60	340
Venezuela	Goat	1	13	4.4	3.7	71
Tunisia	Cow	0.7	26	22	10	120
	Farmyard	2.10	22.5	22.4	8.9	117
	Poultry	< 4	34	< 88	< 44	75

Source: Kumar et al. (2013)

Cd cadmium, *Cu* copper, *Ni* nickel, *Pb* lead, *Zn* zinc environmental impacts by employing methods such as composting, direct combustion, anaerobic digestion, pelletization and vermiculture (Zhou et al. 2019; Zhu et al. 2020a, b). Not only does composting present a low-tech management practice to improve manure's value as a soil amendment and fertilizer, but it also reduces the potential for air and water pollution (Modderman 2019; Lim et al. 2023). Among the major environmental consequences of improper disposal of goat manure is eutrophication, which causes a dense growth of plant life, and high decomposition of plant material which depletes the supply of oxygen, hence leading to animal deaths. On the other hand, biomethane production removes pathogens and odours more effectively, while the digestate produced has a high fertilizer value, thus reducing the environmental impacts of goat manure. Another way of managing excess manure is the introduction of dung beetles (Anderson and Loomis 1978; Arnaudin 2012; Evans 2016; Huerta et al. 2013; Hughes et al. 1975; Ortega-Martínez et al. 2016; du Toit 2022; Wise et al. 2020). Fortunately, in sub-Saharan Africa, there is no need for a debate to introduce beetles (Hughes et al. 1975) because they are native to this environment. Beetles have been used to manage manure, particularly in Australia (Anderson and Loomis 1978; Arnaudin 2012; Hanski 1989) and other parts of the world (Evans 2016; Ortega-Martínez et al. 2016). The move by Australia (du Toit 2022) significantly improved the burying of livestock dung, eliminated the flies' breeding medium, and the control of buffalo and bush flies. In America, dung beetles reduced flies and gastrointestinal parasites in pastures (Wise et al. 2020). To this end, we promote the deliberate breeding of these beetles or at least promote natural breeding in the quest to avoid a looming agricultural and environmental catastrophe. In Nigeria, Chukwu et al. (2022) reported that treatment (anaerobic digestion) of manure before use significantly reduced its potential contamination of both soil and food crops. Although livestock manure has been reported beneficial in SSA, concerns regarding the transmission of pathogens to food crops have also been demonstrated (Burris et al. 2020). *Listeria monocytogenes*, *Escherichia coli* and *Salmonella enterica* are the most common pathogens associated with organic livestock manure fertilizers (Chukwu et al. 2022). Not only is manure a good fertilizer, but microbial analysis of the biofertilizer showed that pathogenic micro-organisms, such were removed by the anaerobic digestion process, thus limiting environmental pollution (Chukwu et al. 2022). Again composting of manure has been shown to reduce zoonotic pathogens like *Salmonella* and *E. coli* (Chukwu et al. 2022); thus in areas where manure is abundant, composting is an environmentally friendly option. The exposure of humans to Respirable Suspended Particulate Matter (RSPM) from fuelwood stoves is a major drawback for the continued use of firewood in rural communities. This smoke creates a health hazard mainly for women and children (Pilloni and Abu Hamed 2021); therefore, deliberate efforts to reduce firewood use are crucial. Algae treatments of raw manure can also improve manure and water quality both of which resolve environmental pollution and carbon sequestration through photosynthesis (Lim et al. 2023). Although such technology is advanced, it can also be tried within communal SSA areas to address climate change as well as reduce irresponsible manure disposal.

Policy and regulatory issues

The lack of appropriate and enforceable regulations in developing countries about the ever-increasing environmental and health hazards, posed by improper manure management, is worrisome. Legislation and policy surrounding manure management (Table 7) in most SSA countries is still under development and all governments are urged to quicken and hasten legislative frameworks for proper manure management. As reported by Ndambi et al. (2019), there are no explicit manure management policies in SSA and different ministries share responsibilities for manure management, which often leads to incoherent policies and abnegation of responsibilities. In some countries, such as Ethiopia, Ghana, Togo, Mali, and Niger; Ethiopia, Nigeria, Togo and Mali; Ethiopia, Nigeria, Senegal and Togo; and Ghana, Nigeria and Togo, ministries regulating zoonotic disease, manure treatment, anaerobic digestion and stocking rate regulation are absent, respectively (Ndambi et al. 2019)). Commercial agriculture in SSA is characterized by specialized cropping or livestock production systems. Coordinated efforts to link the two divergent systems are germane. This, however, is not common for rural farmers, where mixed farming is practised. Nonetheless, manure management strategies are still limiting and efforts to promote simple practices like composting, vermicomposting and algae treatments would improve farmer circumstances immensely. In developed countries like the Netherlands, private organizations overseen by the government are mandated to distribute manure from livestock to crop farms (Wei et al. 2021); such an arrangement has significantly closed the gap between manure producers and consumers, while both benefit from the governing bodies. It would take several decades for SSA countries to develop such a system but concerted efforts towards its achievement are necessary. Regrettably, Ndambi et al. (2019) showed that very few governments provide incentives to smallholder farms for improved manure management especially in West Africa compared to East Africa; the same scenario could be present in most SSA regions. No country in SSA has reported

Table 7 Policy and regulatory comparison, overview of the manure policy framework of 12 sub-Saharan African countries (Teenstra et al. 2014)

Country	Manure policy	Stocking rate	Excretion	Storage	Treatment	Design	Application	Discharge	Agriculture	Environment	Energy	Public health
Burkina Faso	Yes	x	x	x	x	x	x		x	x		
Cameroon	Yes	x	x		x	x	x		x	x	x	x
Ethiopia	Yes	x					x	x	x	x	x	
Ghana	Yes		x	x	x	x	x	x	x		x	
Kenya	Yes	x	x	x	x				x	x	x	x
Malawi	Yes			x	x				x			
Mali	Yes	x	x	x			x		x	x	x	
Niger	Yes	x	x	x	x	x		x	x			x
Nigeria	Yes		x	x		x	x	x	x	x		x
Rwanda	Yes	x	x	x	x				x	x		x
Senegal	Yes	x	x	x	x		x		x			
Togo	Yes						x	x	nd	nd	nd	nd

over-application of manure; in any case, SSA soils are P-deficient and the use of manure will improve available P. At the national level, the optimization and the adoption of biogas technology are at variance in most SSA, for example in Ethiopia the technology was first coined in 1957, but up until now, the uptake is low; in Nigeria, the development, optimization and deployment of biodigesters have slightly been reported (Akhator and Musa 2022). While biogas technology has been reported for most SSA countries, it is surprising to note that feedstock availability and biogas capacity do not tally (Kaifa and Parawira 2019; Akhator and Musa 2022); probably, this is the reason why the technology has not been adopted that much. There is enough information (Mungwe, et al. 2021) about this synergy and requirements; thus, local communities require education as to the effect. Deliberate efforts to promote domestic livestock biogas generation is a required step for absolute energy poverty in SSA, and where such endeavours have been successful, it is by collaboration between government and private players; otherwise, technology abandonment ensues. Another factor limiting the adoption of rural small-scale biodigesters has to do with daily operation and maintenance (Pilloni and Abu Hamed 2021), a scenario not practical for rural communities as it further limits labour availability for fieldwork. In the same vein, the lack of small-scale manure distribution equipment and government subsidies on synthetic fertilizers strongly discourage the use of manure in cropping lands. Setting national manure utilization targets has been coined in China (Wei et al. 2021). The promotion of 'green livestock production', the use of third-party enterprises that facilitate manure exchange between farming communities and a more integrated manure nutrient management approach are genuine requirements for future prosperity. It is noteworthy that the Abuja Declaration (AGRA 2019) on fertilizer for an African Green Revolution had nothing to do with manure as a potential fertilizer that can green Africa substantially and be eco-friendly.

Knowledge gaps and research needs

There is an abundance of resources available for biogas production in many SSA countries. Therefore, it is possible to increase the share of renewable energy in the national energy mix by developing a clear roadmap to include a long-term promotion of biogas technology by involving all the necessary stakeholders at all stages (Arthur et al. 2020). In SSA, several challenges limit the efficient use of livestock manure; in Ghana, extensive treatment of manure is required before it can be used and the reasons for this include poor quality of the manure, unsteady availability and difficulties in manure collection due to poor infrastructure and long distances between farms (Ulrike et al. 2014). Furthermore, in Nigeria, anaerobic digestion of animal manure is not a common practice (Chukwu et al. 2022; Akhator and Musa 2022). The reasons for this could be due to a lack of awareness and appropriate configuration of the treatment system, (Mungwe et al. 2021; Chukwu et al. 2022; Kaifa and Parawira 2019; Arthur et al. 2020; Mwirigi et al. 2014; Usack et al. 2014) and technical skills (Pilloni and Abu Hamed 2021). Nevertheless, the most limiting challenge in rural communities has been winning the confidence and trust of farmers (Mungwe et al. 2021), the lack of it entangled in safety issues. In addition, the chemical analysis of feedstock, in this regard manure, is also critical and most rural farmers have no means to determine this, thus their reluctance to adopt. While animal manure is the best substrate for biodigesters, its lack of carbohydrates requires mixing with other potential biomass wastes to increase harvestable methane gas. The biogas digesters for cold areas are yet to be developed, or even in tropical areas experiencing cold winters, the right technology to maintain the required bio-digester thermal conditions is not available, yet during this time the energy demand is quite high. Interestingly in some parts of SSA, anaerobic digesters are for various reasons, for example in Ethiopia they want to reduce the spread of faecal indicator organisms for environmental stewardship, and in Zimbabwe, it has to do with energy production (Kaifa and Parawira 2019). The contribution of manure to SOC has been scarcely studied; further studies under tropical climate conditions are required (Gross and Glaser 2021). Manuring soils promotes carbon sequestration since soils are the major carbon sinks compared to terrestrial vegetation and the atmosphere combined; this has not been done in SSA. Another policy intervention where mineral fertilizers are replaced by organic fertilizers in the production of fruits and vegetables can be tried since the environmental impact favours organic manure fertilizers (Wei et al. 2021).

Conclusion

Proper manure management is not only beneficial for the environment but also increases the economic value of livestock manure. There is an urgent need to change manure management practices in SSA because current practices are predisposing humans and animals to disease conditions, pose an environmental health risk and are not sustainable. Efforts to increase farmers' knowledge of the proper methods of managing manure are urgently needed. The use of manure as feedstock for anaerobic digesters offers the greatest potential for sustainable management within SSA communities. Just this intervention has ripple effects including energy generation, organic fertilizers and household income generation that emancipates farmers from the poverty trap. The government should encourage the adoption of anaerobic degradation technology in designated areas as this will reduce environmental pollution at the same time generate energy to support rural homes. At the moment, full manure collection and land application, biogas digestion, composting and vermicomposting, recycling and treatment of manures to meet discharge standards are the preferred manure management techniques practised in SSA. The level of intensification and effectiveness of these methods has not been fully determined and efforts to perfect these practices before manure pollution-related hazards strike are imminent. The lack of small-scale manure spreading machinery, manure nutrient analysis system and farmer training guides remain a challenge to proper manure management. Most farmers in SSA do not apply recommended manure management practices, for example, roofing animal housing, having a water-proof floor to ease collection and covering stored manure. This mismanagement leads to large nutrient losses, increased greenhouse gas emissions and reduced quality of organic manure fertilizer.

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