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Manure Management Practices and Policies in Sub-Saharan Africa: Implications on Manure Quality as a Fertilizer

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Manure has been used as a fertilizer since ancient times and if well-managed it can be an asset, promoting sustainable agriculture, and increasing crop production, particularly for smallholder farmers in sub-Saharan Africa (SSA). However, most farmers in SSA do not apply recommended manure management practices, such as roofing animal housing, having a water-proof floor or covering manure during storage, causing large nutrient losses during manure storage, increasing greenhouse gas emissions, and reducing the quality of the manure as a fertilizer. This paper compares manure management practices in representative SSA countries, and summarizes government policies and socio-cultural practices that influence the adoption of good (recommended) manure management practices. Three steps were applied in this analysis: (i) review of manure management practices from various literature sources, (ii) interviews on manure management practices and policies with key stakeholders from 13 SSA countries, and (iii) surveys of manure management practices on small, medium, and large scale farms in Ethiopia and Malawi. The review confirms the potential of manure to improve crop yields and promote sustainable agriculture in SSA. Unfortunately, most SSA countries (a) do not explicitly mention manure management in their policies (b) have different ministries that share responsibilities on manure management, often leading to incoherent policies and abnegation of these responsibilities (c) take limited action to promote good practices or enforce legislation on manure management. Also, the field survey indicated that farmers lack knowledge on manure management. However, farmers are able to access agricultural extension services from both government and non-government agencies, although these extension services rarely included information on improved manure management practices. Extension services that encourage exchange and interaction between farmers were most successful in increasing adoption of good manure management practices, and are recommended. In addition, efforts to improve manure management in SSA should strengthen the enforcement of existing policies and provide an enabling environment for adoption of good manure management practices.

Keywords: greenhouse gas emissions, manure management, practices, policies, sustainable agriculture, Sub-Saharan Africa

INTRODUCTION

Sub-Saharan Africa (SSA) has the highest prevalence of undernourishment and the highest rise in proportion of people who are food insecure (FAO et al., 2017), with soil nitrogen (N) availability singled out as a major constraint to crop production in many areas of SSA (Liu et al., 2010). Because of low (on average $\leq$8 kg N ha^{-1} yr^{-1}) fertilizer application rates (Alexandratos and Bruinsma, 2012; AGRA, 2013), there is a higher N uptake by crops than the N input from fertilizer (Zhou et al., 2014). This mining of nutrients contributes to soil depletion which then limits agricultural sustainability.

A potential major nutrient source for smallholder farmers who cannot afford mineral fertilizers could be livestock manure (Tittonell et al., 2010). Manure contains important plant nutrients such as N, phosphorus (P), potassium (K), and other secondary nutrients and trace elements, with farmers all over the world having discovered its benefits and associated it with increased crop production as far back as 5900–2400 years B.C. (Schoenau, 2006; Bogaard et al., 2013). The application of animal manure to soils, unlike synthetic fertilizers, also provides organic matter that can enhance infiltration rates, improve water holding capacity, increase cation-exchange capacity (Schoenau, 2006), and increase soil C (Kim et al., 2011; Gattinger et al., 2012; Maillard and Angers, 2014). Various studies have been conducted in SSA showing the positive effects of manure application on crop yield (**Table 1**), however effective use of livestock manure as a fertilizer depends critically on methods of manure handling and storage, and on synchronizing mineralization of manure N with crop uptake (Rufino et al., 2006).

Integrated Manure Management (IMM) mainly involves improved practices in collection, treatment, storage, and application of manure to soils (Teenstra et al., 2015) that can not only improve yields, but can also have other co-benefits, such as reducing nitrate (NO_3^-) and phosphorus (P) leaching, as well as reducing both ammonia (NH_3) volatilization and nitrous oxide (N_2O) and methane (CH_4) emissions (IAEA, 2008; Hristov et al., 2013; Tubiello et al., 2014). **Figure 1** shows a nutrient cycle for crop-livestock systems which is suitable for SSA countries. Poor manure management might also lead to transfer of zoonotic diseases to humans and may pose a public health threat especially where livestock is kept in urban and peri-urban areas (Manyi-Loh et al., 2016; Ström et al., 2018). Due to public health concerns, the GlobalGAP forbids the application of untreated manure on leafy vegetables once they are planted and restricts manure application to 60 days before harvesting for other crops (GlobalGAP, 2015). Poorly discharged manure can lead to contamination and eutrophication of surface and ground water mainly with nitrate. High nitrate concentrations in drinking water detrimentally affects health of especially infants and elderly persons and is common in southern Africa (Tredoux and Talma, 2006; Martinez et al., 2009).

To optimize the benefits from manure, farmers need to adopt practices that efficiently integrate manure use in crop production. The adoption of new farming practices in SSA is strongly influenced by agricultural extension services that are often regulated by government policies (Teenstra et al., 2014). This implies that studies on efficient adoption of improved manure management practices should consider the role of the government and extension services.

The aim of this paper is to describe current manure management practices and policies in SSA countries, to discuss the factors that affect manure use as a fertilizer and to provide suggestions on how to improve manure management practices and policies in order to promote agricultural sustainability in the region.

TABLE 1 | Comparison of yield improvement of various crops due to manure application in different countries in SSA.

Country	Source	Crop cultivated	Manure type	Application rate (t/ha)	Crop yield increase (t/ha)
Nigeria	Abunyewa, 1997	Maize	Cattle manure	6 t/ha	2.4 vs. 1.1
Nigeria	Ikeh et al., 2012	Peper (Capsicun frutescens)	Poultry manure	6 t/ha	17.03 vs. 8.22
Zimbabwe	Zingore and Giller, 2012	Soybean	Cattle manure	14 t/ha	1.18 vs. 0.57
Nigeria	Enujeke, 2013	Water melon	Poultry	5 t/ha	422.8 vs. 245.2
Malawi	Mathias and Kabambe, 2015	Cassava	Cattle manure	5 t/ha	27.61 vs. 21.90
Zambia	Biratu et al., 2018	Cassava	Poultry	4.2 t/ha	28.5 vs. 19.8

NB, The table has extracted only results which compare manure application to a control with neither manure nor fertilizer application.

METHODOLOGY FOR ANALYSES ON MANURE MANAGEMENT IN SSA

Two sets of interviews were used to determine the current state of manure management practices and policies:

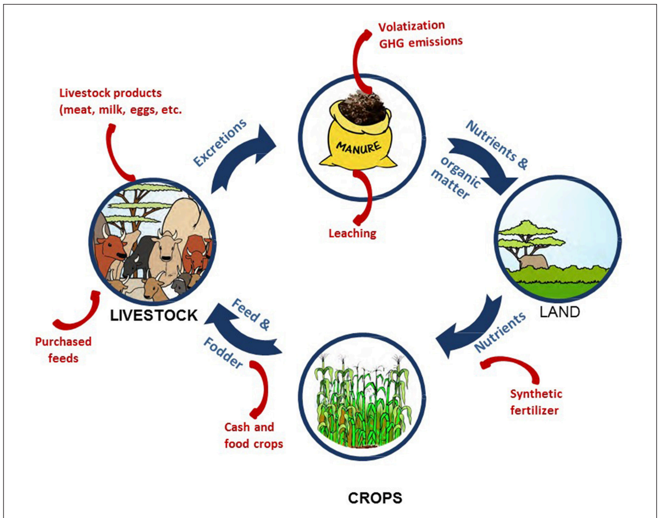

FIGURE 1 | Nutrient cycle in crop-livestock systems.

1. Interviews with stakeholders (e.g., government officials and researchers) from 13 SSA countries using two general questionnaires,
2. In depth field analyses in Ethiopia and Malawi involving interviews with farmers and extension workers.

In addition, we searched existing literature with the Wageningen University Library and Google Scholar using the following keywords: manure, management, practices, policies, sustainable agriculture**,** sub-Saharan Africa, and the names of the 13 countries. The search was also done in French for French-speaking countries.

General Questionnaires

Two general questionnaires were sent to corresponding partners from 13 countries in SSA. The countries were selected to provide sufficient representation from East, South and West Africa, and included Ethiopia, Kenya, Malawi, Rwanda, Zambia, Cameroon, Ghana, Nigeria, Senegal, Togo, Mali, Burkina Faso, and Niger. The first questionnaire consisted of questions regarding current manure management practices, stakeholders involved, and their level of engagement. Respondents answered questions for each ministry in their countries responsible for activities related to manure management. These included questions on regulations regarding stocking rates, manure storage and treatment, anaerobic digestion, manure application, air pollution, water pollution, spatial planning of farms, and zoonotic diseases. The second questionnaire captured how the political environment influences the adoption of improved manure management practices. Interviewees were selected with the support of government officials from the Ministry of Agriculture, Ministry of Environment, and through the UNFCC focal point in the respective countries and were conversant with manure management policies and practices in their respective countries. Two respondents were selected per country, each from a separate ministry or NGO, responding individually to the questionnaires. All respondents were then conveyed to a face-to-face meeting where their original responses were validated through discussions among respondents from the same country and also through interaction with respondents from different countries.

In-depth Analysis

In-depth field surveys were conducted in only two countries: Ethiopia and Malawi. Two regions with higher livestock densities than the national average were selected in each country. Farmers were selected with the help of local agricultural extension workers, and covered three production scales (small, medium, and large scale). A medium scale farm was defined as a farm with 8–30 TLU (Tropical Livestock Unit = 250 kg live weight) of ruminants, or 50–200 live poultry or 25–100 live pigs. Farms with fewer animals were considered as small scale, while those with more animals were considered to be large scale. A total of 23 farmers from Ethiopia and 20 farmers from Malawi were selected. Additionally, six prominent extension workers, three from each country, and working in the selected study regions were interviewed using a semi-structured questionnaire with both open- and close-ended questions. Interviews with extension workers gave a general understanding of the study environment, farming, and extension systems, while the interviews with farmers enabled a better understanding of the livestock production systems, housing, collection, treatment, storage, and application of manure as well as farmers' opinions regarding manure management.

Research Ethics

This research was conducted in accordance with the Netherlands *Code of Conduct for Scientific Practice*, with the additions and qualifications from the *Wageningen* UR Ethical Guidelines. An ethics approval was not required for this study because it was not using humans or animals as subjects. Respondents at national level had a written informed consent by email and had the option to accept or decline their participation in the study. Interviewed farmers did not have a written informed consent, but were given an opportunity to decide whether to, or not to participate in the survey after a brief introduction about the purpose and content of the survey. Sensitive data (i.e., individual name, phone number, farm house location) were kept separate from the generic data and only people involved with the project could access this information. This study has not been previously published and is not under consideration for publication elsewhere. Necessary permissions have been taken for all material used in this article.

MANURE POLICIES AND ENABLING ENVIRONMENT IN SUB-SAHARAN AFRICA

Overview of Manure Policies in Selected SSA Countries

In four of the countries surveyed (Kenya, Malawi, Rwanda, and Burkina Faso) there was at least one ministry responsible for all of the activities, while Cameroon, and Niger had ministries responsible for eight of the nine activities, with Cameroon lacking a responsible ministry for regulations on manure storage and Niger lacking a responsible ministry for regulations on spread of zoonotic diseases. The four activities with the fewest responsible ministries in the studied countries were (*i) Zoonotic disease regulation* (responsible ministries absent in Ethiopia, Ghana, Togo, Mali, and Niger), (*ii) manure treatment regulation* (responsible ministries absent in Ethiopia, Nigeria, Togo, and Mali), (*iii) anaerobic digestion regulation* (responsible ministries absent in Ethiopia, Nigeria, Senegal, and Togo), and (*iv) Stocking rate regulation* (responsible ministries absent in Ghana, Nigeria, and Togo).

However, even though most surveyed countries had ministries responsible for most livestock manure related activities, this does not mean that the regulations were effective. In most cases, the replies to the general questionnaire can be summarized into three main points:

a) *Policies do not always explicitly mention livestock manure management, but it is often considered as a component of waste management. Therefore, the responsibility for managing this resource is often shared by different ministries, leading to incoherent policies, and abnegation of these* *responsibilities.* Some countries including Kenya, Malawi, Rwanda, and Burkina Faso have ministries responsible for all the selected management activities. However, they have no explicit manure management policy. For example, in Senegal's MP the Ministry of Agriculture and the Ministry of Environment both have responsibilities on manure management. However, enforcement of these policies are weak, leading to a minimal burden of manure policies on the farmers (Teenstra et al., 2015).

b) *Animal waste is often regarded as a source of pollution and a potential human health risk, not as a resource to be utilized.* In most SSA countries, more consideration is made on animal waste as a risk to human health than its potential as a fertilizer. For example, the Rwanda Environmental Management Authority (REMA) considers animal wastes as a potential water pollutant and a potential cause of diseases like typhoid fever, cholera, and dysentery (REMA, 2009). In Burkina Faso, the environmental law from the ministry of Environment mandates the ministry of Animal Resources to control hygiene of animal products and potential sources of pollution from livestock activities including manure (Yeye, 2000).

c) *Even when policies exist, enforcement can be a challenge. Countries take limited action to promote good practices or to enforce legislation on manure management*. The availability of a responsible ministry in a country does not necessarily lead to effective manure legislation, control, and enforcement. Malawi for example has ministries responsible for all assessed activities; however their enforcement has been lacking (Makawa, 1998; IBAHRI, 2012).

On the other hand, there are initiatives supporting the construction and use of manure in smallholder biogas plants generating energy for cooking and lighting. These are widely promoted as a way to reduce deforestation, decrease labor demands for women and children and improve respiratory health of women (NBPE, 2007; ABPP, 2018). This is also the case with the SNV funded African Biogas Partnership Programme (ABPP) covering five countries: Burkina Faso, Ethiopia, Kenya, Tanzania, and Uganda (ABPP, 2018), and the Green growth and Climate resilience program in Rwanda (GGCR, 2011). Meanwhile, in Kenya, other private organizations offer services which facilitate the use of manure management to promote sustainable agriculture (SGS, 2017).

Enabling Environment

The previous paragraphs show that in SSA countries, manure management policies are not explicit enough to oblige or encourage farmers to benefit from the nutrients in manure. There are however other factors that might discourage the use of manure as a fertilizer, especially its bulky nature. In Ethiopia for example, Ketema and Bauer (2011) showed that crop farmers who could afford synthetic fertilizers had lower rates of manure use because they found manure application to be more laborious in comparison to synthetic fertilizers. This implies that policies that subsidize the cost of synthetic fertilizers may discourage the use of manure, if incentives are not made for manure use.

The results show that all farmers, regardless of farm size, were able to access training, and extension services from both government and non-government agencies (**Table 2**). There were differences in the level of privatization of the extension services with a dominant public sector extension in most countries, with the exception of Kenya, which has a stronger private sector extension service, and Malawi, which has a mix of both (Mulanga and Jayne, 2006; Bernahu, 2012; Simpson et al., 2012). The extension services from both the government and private sector were available for farmers of all production scales, although there was a focus on smallholder farmers in most countries. Respondents highlighted that although these services existed, manure management was rarely covered by the extension scheme. Based on case studies in the various countries, respondents revealed that most farmers who adopted improved manure management practices had seen other farmers successfully implement the adopted practices. We concluded that the most effective extension services in disseminating good manure management practices were those with demonstrations that allowed farmers to see what fellow farmers were doing. Ethiopia and Malawi used lead farmers to carry out various manure management activities such as proper collection and storage, bio-slurry fertilization, composting, and application of manure on crop farms. These farms were then used as demonstration and training sites where other farmers could appraise the difference between crops in an integrated manure management system and those without.

Subsidies also tend to be available to farmers of all production scales, although this is more often the case in Eastern Africa compared to Western Africa. In Western Africa, it was common to have agricultural subsidy programs that have been mismanaged and sometimes abandoned as was observed in Cameroon, Togo, and Niger (Fonjong, 2004; Le Magadoux et al., 2013; Mackiewicz-Houngue, 2014), suggesting that adequate agricultural financing is likely a common challenge in Western Africa. It was also noticed that Non-government organizations (NGOs) were more focused than governments in providing incentives to smallholder farms for improved manure management.

RESULTS OF THE IN-DEPTH ANALYSIS ON MANURE MANAGEMENT PRACTICES IN ETHIOPIA AND MALAWI

Brief Overviews on the Livestock Production Systems in Ethiopia and Malawi

In **Ethiopia**, cattle are the dominant livestock species as goats are poorly adapted to the cold conditions at high altitudes and pork is not consumed by people associated with the dominant orthodox religion (Tekle et al., 2013). Farmers of the landless systems closer to major urban centers have a higher proportion of crossbred cattle with higher milk yield (Tegegne et al., 2013). Further away from the urban centers, livestock systems are mainly mixed with crop production, which is typically the major source of income. In these areas, livestock management is less intensive, with the animals grazing during the day and brought back to a compound

TABLE 2 | Availability of services that enable the adoption of improved manure management practices to small, medium, and large farmers in selected sub-Saharan African countries.

	Ethiopia	Kenya	Malawi	Rwanda	Zambia	Cameroon	Ghana	Nigeria	Senegal	Togo	Mali	Burkina Faso
Subsidy by government	S				S M	M L						M L
Subsidy by non-government		S		S	S	S						
Credit by government					L							
Credit by non-government	S	S M L	S		S	S						
Guarantee for credit by government	S			M L	S							
Guarantee for credit by non-government			S M	S	L	S M						
Vocational training		S M L	S	S M	S M	S M	S M L	S M L			S M L	S M L
Extension/advice by Government	S	S M L	S M L	S M	S M L	S	S M L	S M L	SML	S M L	S M L	S M
Extension/advice by non-government	S	S M L	S M	S M L	S M L	S		S M L	SM L	S M L	S M L	S

Codes: S, Smallholders (<8 TLU); M, Medium scale farmers (8–30 TLU); L, Large scale farmers (>30 TLU). 1 TLU (Tropical Livestock Unit), 250 kg live weight.

at night. The overnight housing of animals (especially cattle) in the various confinement systems (**Table 4**) is not only meant to shelter the animals but, most importantly, to protect the animals from theft and predators. Most cattle owners in these district also own sheep, while poultry production is predominantly (95%) in traditional systems where chicken scavenge around households for their food (Wilson, 2010).

In **Malawi**, farming systems are typically a mix of annual crops, which provide most of the farm income, with a combination of different livestock species including cattle, goats, pigs, and chickens. In general though, cattle are considered by farmers to be the most important. Tobacco is a common cash crop, while forest plantations and unmanaged shrub land were common as well. Communal land, where many of the farmers take their cattle each day to graze, was also noted. The number of landless farms was very low and was limited to pigs, poultry and occasionally dairy cattle. Farms also tended to have good access to markets because government-run livestock markets were established in regions that are far from major centers.

Animal Confinement and Manure Management Practices in Ethiopia and Malawi

In Malawi, most of the farms that used confinement systems that combined fences and roofs (and occasionally a concrete floor) were for pigs, poultry, and small ruminants (**Figure 2**). In the large laying hen operations the chickens were confined all day. Pigs and dairy cattle were also confined most, if not all, of the day. The confining of dairy cattle seems to be a result of information from the extension workers as many respondents confirmed that some extension workers put strong emphasis on the confinement of dairy cattle. However, a majority (56%) of the cattle farms that had ma/inly beef cattle only have fences without a floor and roof. Similar to Ethiopia, the beef cattle are taken out to graze in the morning and return to the pen shortly before dusk. This means that not all manure can be collected and most of it stays on the grazing land and around the homesteads.

The results of the manure management practice surveys in Ethiopia and Malawi are shown in **Table 3**, which shows that the use of bedding material is more common in Malawi than in Ethiopia. Less use of bedding material implies that nutrient conservation in manure will likely be reduced (see section Implications of Livestock Systems and Manure Management Practices on Manure Quality as a Fertilizer in SSA). The digestate (i.e., bio-slurry from biodigesters) can be used as a fertilizer, however only 25% of Ethiopian farms with biodigesters used the digestate as a fertilizer, while all farmers in Malawi used the digestate as a fertilizer. In Ethiopia, the large farms with biodigesters discharged most of the digestate into waterways while the smaller farms dried it to obtain dung cakes used for cooking. In Ethiopia, manure is the preferred fuel source for cooking the national food (*injera*) because it burns slowly with a desirable deep heat required for cooking injera. However, research is ongoing to produce stoves that can cook *injera* using the biogas from the digesters.

Urine storage is uncommon both in Ethiopia and Malawi, likely because the predominant confinement systems do not include an impermeable floor, and so the urine tends to infiltrate the soils underlying the kraal. This means that a huge amount of nutrients (notably nitrogen and potassium) is lost, potentially damaging the local environment. In both countries, manure is generally stored as a solid. In Ethiopia almost all farms stored and dried solid manure that was later used for fuel, while over two thirds of the farmers in Malawi stored solid manure for later use as a fertilizer. In both countries smaller and medium scale farms were more likely to use manure as a fertilizer than the larger farms because small and medium farms also tended to have cropland while large farms primarily focused on livestock with limited or no cropland. Additionally, none of the interviewed farms in Ethiopia and Malawi had waterproof floors nor roofing/cover for manure storage, exposing it to additional nutrient losses.

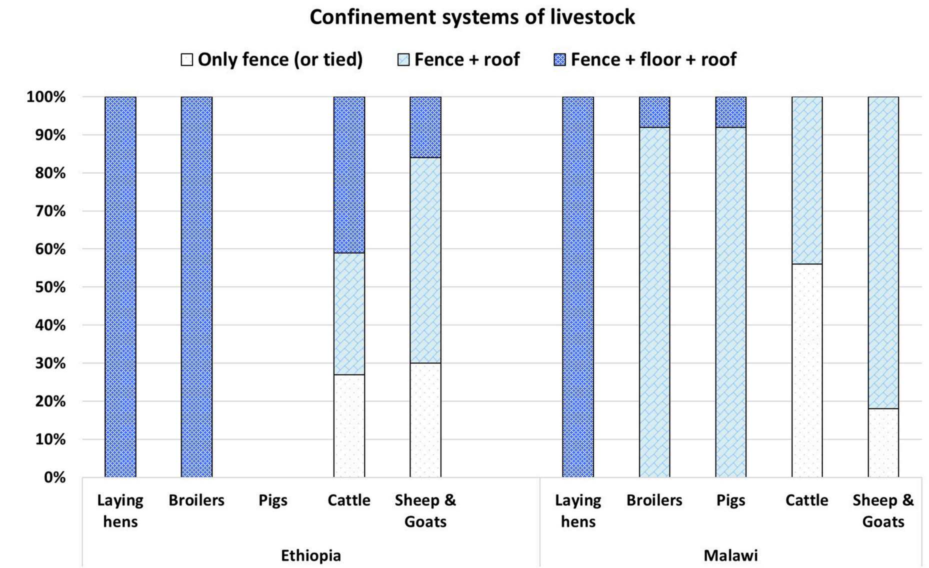

FIGURE 2 | Proportion of farms in Ethiopia and Malawi keeping their animals in different confinement systems including fencing, roofing and flooring options.

Scavenging animals, in particular the chickens, deposited most of their manure around the household, which was not usually collected. In the Awassa region of Ethiopia, it was common for farmers with indigenous cattle breeds to go on transhumance with their animals (including small ruminants) for up to 3 months, leaving behind the rest of the family. This means that the use of biodigesters would not be feasible here because the digester requires daily feeding with fresh manure. Also, the manure produced during the migration will be left directly on the pasture fields, serving as a fertilizer.

In **Ethiopia**, poor manure management is typically related to insufficient labor at the farm, particularly with liquid manure where transportation was very laborious. Some farmers though, mixed the liquid manure with crop residues and other materials to make compost, which is generally easier to transport. Technical issues (such as a lack of equipment, storage capacity, trading infrastructure, etc.) were not considered as constraints to improved manure management. About one third of the farmers in Ethiopia had invested money in improving manure management within the last 5 years and were happy with the outcome of their investments (mainly higher crop yields). These farmers mentioned that these investments mainly were the result of them being convinced by other farmers rather than by agricultural extension workers. However, exchange of information among farmers was limited to small geographical areas, narrowing the possibilities of farmers to learn from others, reducing the adoption rate of recommended manure management practices.

The agricultural extension system has not sufficiently included manure management in its training scheme and there currently is a procedural disincentive for extension workers to educate farmers on improved manure management. Extension workers are judged and promoted partly based on the volumes of synthetic fertilizer they sell. As farmers tend to buy less synthetic fertilizer when they use more manure, extension workers do not always promote field application of manure. It is recommended that the extension system revise their criteria for compensating extension workers, for example based on increased crop yield per hectare.

In **Malawi**, most of the farmers believed the most crucial constraint to enhanced manure management was the lack of information. They did not have sufficient knowledge on manure management practices and their potential benefits. However, farmers did recognize that manure was useful as a fertilizer and most said that it was crucial for them. Most of them mentioned that synthetic fertilizers are expensive and that the use of manure allows them to purchase less fertilizer. Like in Ethiopia, about a third of the large scale farmers in Malawi had invested time or money over the last 5 years in improving manure management. Because these farms usually don't own cropland, it would be advisable for them to prepare compost manure which is marketable and easier to transport than fresh dung. Commercial compost producers could also buy large volumes of manure from large scale farmers and process and sell it to large scale crop farmers.

IMPLICATIONS OF LIVESTOCK SYSTEMS AND MANURE MANAGEMENT PRACTICES ON MANURE QUALITY AS A FERTILIZER IN SSA

The nutrient composition of manure at the moment of land application and its potential to provide nutrients for plant growth is dependent on the initial nutrient content of manure and on its management (Lekasi et al., 2002; Jokela and Meisinger, 2004; Kupper et al., 2014; Roy and Kashem, 2014). The original nutrient content of manure depends primarily on the animal

TABLE 3 | Description of manure management in Ethiopia and Malawi using proportions of farms carrying out various practices.

		Ethiopia			Malawi		
		Large	Mid	Small	Large	Mid	Small
	Number of farmers interviewed	11	7	5	12	5	3
1	Fraction of farms using bedding material and which is removed while mixed with animal excretions	9%	0%	0%	42%	20%	33%
2	Fraction of farms using anaerobic digestion	27%	14%	0%	0%	40%	67%
3	Fraction of digestate (bio-slurry) used for on-farm crop fertilization?	25%	0%	0%	100%	100%	100%
4	Fraction of digestate used for off-farm crop fertilization (sold or given away)	0%	0%	0%	0%	0%	0%
5	Fraction of farms discharging the digestate	75%	0%	0%	0%	0%	0%
6	Fraction of farms storing urine (separate from dung and for a longer period)	18%	14%	0%	0%	0%	0%
7	Fraction of urine storages with waterproof floor and walls	50%	0%	0%	0%	0%	0%
8	Fraction of urine storages with roof/cover	50%	0%	0%	0%	0%	0%
9	Fraction of stored urine used for on-farm crop fertilization	0%	0%	0%	0%	0%	0%
10	Fraction of farms storing liquid manure (slurry, a mixture of urine and dung)	0%	0%	0%	8%	40%	67%
11	Fraction of liquid manure storages with waterproof floor and walls	0%	0%	0%	0%	0%	0%
12	Fraction of liquid manure storages with roof/cover	0%	0%	0%	0%	0%	0%
13	Fraction of stored liquid manure used for on-farm crop fertilization	0%	0%	0%	8%	20%	33%
14	Fraction of farms storing solid manure	91%	100%	100%	42%	80%	67%
15	Fraction of solid manure storages with waterproof floor?	0%	0%	0%	0%	0%	0%
16	Fraction of solid manure storages with roof/cover	0%	0%	0%	0%	0%	0%
17	Fraction of stored solid manure used for on-farm crop fertilization	25%	40%	30%	83%	100%	75%
18	Fraction of stored solid manure used for off-farm crop fertilization	0%	0%	0%	17%	0%	25%
19	Fraction of stored solid manure used for fuel	75%	60%	70%	0%	0%	0%
20	Fraction of farms which improved their manure management (storage, treatment, application) in the past 5 years?	27%	29%	40%	33%	80%	17%

species (or breed) and feeding practice/feed quality. **Table 4** shows the average composition of different manures, where poultry manure contains the highest nutrient concentrations. In general, monogastrics (poultry, pig) produce manure of higher nutrient content as compared to ruminants (cattle, goat, sheep). Though, by quantity most of the manure available on farms in SSA is from ruminants. Manure management meanwhile, can affect manure quality by changing the effects of environmental conditions (e.g., temperature, rainfall, humidity, wind) that are known to affect nutrient loss rates from manure (Lorimor, 2015; Owen and Silver, 2017).

Livestock Feeding and Manure Quality

The quality of manure largely depends on the quality of the feed (e.g., digestibility, protein content, etc.) and by the processing (e.g., pelleting, extrusion, steaming, ensiling, fermenting, and grinding). Pasture grasses from tropical regions including SSA usually contain more lignin compared with grass from temperate regions (Van Soest, 1994), which reduces the digestibility. In grassland based systems in SSA, particularly during the dry periods, animals consume low quality grass, and straw (Lamy et al., 2012), which has been linked to excreta (dung + urine) with low N contents (Pelster et al., 2016), reducing in a poorer quality fertilizer. The processing of the feeds also affects the digestibility and therefore the feed efficiency (Stark, 2012). In SSA, feed processing is most commonly practiced in medium and large-scale landless cattle farms where the use of concentrate feed is highest. In Kenya for example, some of these farms possess their own mechanical or electrical grass chopper, to make the feed finer facilitating nutrient absorption and hence reducing the manure volume and nutrients excreted (Kiptot et al., 2015).

Manure Collection

Collecting a mixture of bedding material, feed waste, flushing water, feathers, soil, etc. together with animal excreta will also affect the nutrient content. Bedding can conserve nutrients in manure if it partly covers the manure and can prevent ammonia volatilization (KATC, 2004). Collecting manure with beddings can also result in manure with lower mineral N concentration and higher C:N ratio because the bedding materials (e.g., straw) usually have lower N concentration than the animal excreta (Lekasi et al., 2002). Increasing the C:N ratio will result in greater rates of N immobilization by soil microbes (USDA, 2011) reducing volatilization losses, although proper timing of application is critical as the N immobilization by microbes may reduce N availability for the growing crop. For the two surveyed areas, there were three manure categories that can be distinguished: (a) *Liquid manure (slurry):* collecting a mixture of feces and urine in liquid form where the animals are most often kept on slightly sloping solid floors that are regularly cleaned and flushed with water; (b) *Mixed manure:* comprising both solid and liquid manure streams from animals kept on bedding material. (c) *Solid manure:* excreta from animals collected as solids with or without bedding material (Martinez et al., 2009; Lenkaitis, 2012).

TABLE 4 | Nutrient quality of solid and liquid manures (g/kg) from various animal species expressed as a range and as an average proportion of nitrogen, phosphorus and potassium.

Manure type		Dry-matter (%)	Kg per ton fresh matter (=g/kg)				
			N total	NH_4^+-N	P_2O_5	K_2O	Mg
SOLID MANURES							
Solid cattle manure	Range	16–43	2–7.7	0.5–2.5	1.0–3.9	1.4–8.8	0.7–2.1
	Average	22	4.8	1.3	3.0	5.7	1.1
Solid sheep and goat manure	Range	25–48	6.1–8.6	1.3–2.6	2.3–5.2	5.7–16	1.1–3.5
	Average	30.6	7.8	2.0	4.0	9.9	2.1
Solid pig manure	Range	20–30	4–9	0.7–6	1.9–9.2	2.5–7.2	0.5–2.5
	Average	24	6.8	2.4	6.3	4.9	1.4
Solid broiler manure	Range	45–85	18–40	2–15	6.9–25	6.7–23	2.5–6.5
	Average	60	30	7.6	18.5	17.1	4.2
Solid layer manure	Range	22–55	13–45	5–25	8–27	6–15	1.2–6
	Average	40.6	23.6	10.9	16.6	10.7	3.1
LIQUID MANURES							
Pig slurry (no added water)	Range	1.5–15.7	2.5–10.6	1.3–5.5	0.3–11.9	2.4–10.8	0.2–3.0
	Average	7.4	6.5	3.6	3.9	6.8	1.5
Cattle slurry (no added water)	Range	3.4–20	2.4–7.8	0.2–4.4	0.6–7.7	1.2–9.1	0.6–2.7
	Average	9.6	4.9	2.4	2.0	6.2	1.4
Pig bio slurry (no added water)	Range	1.2–12.9	2.5–10.6	1.6–6.9	0.3–11.9	2.4–10.8	0.2–3.0
	Average	6.1	6.5	4.0	3.9	6.8	1.5
Cattle bio slurry (no added water)	Range	2.8–16.5	2.4–7.8	0.3–5.1	0.6–7.7	1.2–9.1	0.6–2.7
	Average	7.9	4.9	2.8	2.0	6.2	1.4

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Source: (Teenstra et al., 2015).

Manure Treatment

The three most common ways of treating manure in sub-Saharan Africa include drying (active and inactive), solid storage, sometimes with active composting, and anaerobic digestion.

i. *Drying*: When manure is left in heaps on natural earth for a long period, it might dry up.

Drying is advantageous to the manure user because it reduces the bulk of the manure and facilitates transportation, is odor-free and it is also cheap. However, there are some disadvantages of drying manure such as high losses of nutrients especially nitrogen, possibility of dried manure to carry pathogens, and seeds of weeds. Dried manure might be lumpy in large pieces that need to be broken before application as fertilizer. If dried manure is burnt for fuel, nitrogen, and organic matter are lost, but the ashes can be used as (P and K) fertilizer.

ii. *Composting:* Compost is an organic fertilizer prepared through aerobic decomposition of organic matter from plant and animal origin. It is an attractive option for turning on-farm organic waste materials into a valuable farm resource (Inckel et al., 2005). Composting requires labor, but compost is an excellent soil improver and is cheaper than other soil amendments. By providing organic matter and soil nutrients, compost improves the structure of the soil, allowing for better aeration, improving drainage, nutrient and water retention, and reduced risk of erosion (Inckel et al., 2005; Edwards and Araya, 2011). Composting of manure is common in most parts of Africa, though the method of composting and the degree of process control might vary from farm to farm and from country to country (Edwards and Araya, 2011).

iii. *Anaerobic digestion:* Anaerobic digestion (AD) is a low-oxygen biological process that results in the production of a gas (biogas) which is a mixture of methane (60–65% CH_4) and carbon dioxide (35–40% CO_2) that can be collected and stored for use (e.g., for cooking or lighting), making AD a practical option for rural energy supply (NBPE, 2007; Comparetti et al., 2013; Warnars and Oppendoort, 2014). During the process, a portion of the organic nitrogen (slow release N) will be transformed into ammonia nitrogen (fast release N). The production and emissions of the biogas means that bio slurry has a lower C:N ratio than the input manure, however the transformation of the organic N to mineral form means that the slurry also has a higher proportion of fast release ammonium nitrogen (Vu et al., 2015) making bio-slurry a particularly effective N fertilizer.

The potential of biogas production in reducing GHG emissions has been debated by previous authors. The Netherlands Development Organization for example, states that one biogas plant has the potential to reduce 4t CO_2 equivalents of emissions per year (NBPE, 2007) and produce bio-slurry (described in **Table 5**) which is a rich fertilizer (Warnars and Oppendoort, 2014). On the other hand, Bruun et al. (2014) stated that

TABLE 5 | Summary of advantages and disadvantages of major manure management options in SSA.

Manure treatment	Brief description	Advantages	Disadvantages
Fresh application (solid and liquid manure)	Direct application of either solid or liquid fresh manure to pastures or crops	• Fresh manure, like any other form of organic manure improves the structure of the soil which allows better aeration of the soil, improves drainage, and reduces erosion. • Manure nutrients become slowly available as plant food and can have effects on crops for several years. • Good crops can be obtained with reduced need for extra chemical inputs.	• Minerals from manure may not be immediately available to plants; mainly for ruminant manure. • There can be a mismatch in time between nutrient release and plant uptake; • Risks associated with transmission of zoonotic diseases if crops are consume; • Seeds of weed can be transferred to the field trough fresh manure.
Drying	When manure is left in heaps on natural earth for a long periods till it dries up. Manure is also actively molded and dried for fuel in some countries like Ethiopia	• Drying makes manure less bulky and easier to transport. • Dried manure contains organic matter that provides similar advantages of using organic fertilizer as in fresh manure.	• During drying, nitrogen is lost from manure through volatilization of NH3. • Also, if dried manure is not protected from rain, rewetting events can lead to GHG emissions. These N losses will also result in a poorer quality fertilizer. • Nitrogen and organic matter are lost when manure is used as fuel
Composting	Composting is an active process of preparing organic fertilizer. Manure is usually combined with plant material and left to undergo aerobic decomposition.	• It provides the same advantages of organic fertilizers to the soil as manure and in addition: • It is less expensive compared to other soil amendments. • It is less bulky and easier to transport than fresh manure • Composting makes it easier for plants to take up the nutrients in the soil. • Composting exposes manure to high temperatures that reduce pests, diseases, and destroy weed seeds in fresh manure. • Large amounts of vegetation, such as crop remains, garden weeds, kitchen, and household wastes, hedge cuttings, garbage, etc., can be put to use. • Compost is odorless as compared to manure	• Compost preparation is time consuming. • Most of the nitrogen from manure is lost during composting. • High nitrous oxide emissions • Water is required for compost making and it is a difficult option during the dry periods or in areas where water is scarce. • Composting requires large amounts of high carbon material (usually straw or crop residues) which might not be available at some times of the year
Anaerobic Digestion (with use of bio-slurry as fertilizer)	This is the conversion of manure by anaerobic bacteria into biogas and digestate. The digestate which is also called bio-slurry is a mixture of digested dung and water having a dry matter content of ∼7%.	• Provides energy and fertilizer value is maintained or even enhanced. • It provides the same advantages of organic fertilizers to the soil as manure and in addition: • Reduce labor especially of women and girls who spend many hours searching for fuel wood. • Reduce cost on purchase of synthetic fertilizers, which will be (partly) replaced by the bio slurry • Lower risk of infection due to the hygenization during digestion Affordable lighting in rural (for learning and doing house chores in the evenings) • Reduce risk of respiratory diseases linked to the use of fuel wood, dung cakes, and charcoal. • Reduced greenhouse gas emissions as the produced CH_4 is captured and used for cooking. • Bio-slurry is odorless as compared to manure	• This requires a very high initial investment, often not affordable to smallholder farmers, except though subsidies. • It requires continuous availability of water. • Requires frequent feeding of manure • Liquid digestate is more difficult to manage than dried manure due to high water content

Source: The table is based on data from Inckel et al. (2005), NBPE (2007), Bruun et al. (2014), Warnars and Oppendoort (2014) and Vu et al. (2015) authors' experiences.

biogas digesters are often poorly managed and that there is a lack of proper distribution system for biogas. This results in unintentional release of methane through leakages, and intentional flaring of the gas during surplus production periods (Bruun et al., 2014), with a risk of increasing, instead of reducing GHG emissions (Vu et al., 2015).

Several countries in SSA have biogas programs to promote the use of biogas by livestock farmers (ABPP, 2018). However, the adoption of biogas technology by livestock farmers in SSA has been limited mainly due to high investment costs and lack of management skills, although current programs usually have some subsidies as incentives to help farmers overcome the high investment costs (NBPE, 2007; Ngigi, 2010). Ethiopia for example has a relatively high adoption rate of biogas compared to other African countries due to aggressive government policies combined with incentives including subsidization of construction costs.

Manure Storage

There are many different manure storage systems (Lekasi et al., 2002), however in SSA, smallholder farmers tend to use solid storages with no collection or storage of urine. In the kraal systems where animals graze freely during the day and spend the nights inside the kraal, the manure is managed as a drylot system where the animals deposit much of the manure in the kraal where it is allowed to pile up before infrequent collection. In other systems where animals are confined (such as in zero-grazing), dung is collected and stored in heaps, mostly without a hard floor or cover. Liquid manure systems, such as silos, pits or lagoons are applied primarily with the anaerobic biodigesters or in conjunction with larger scale, and highly mechanized systems. Opio et al. (2013) estimated the frequency of the various cattle manure storage systems as defined by IPCC (2006), in order to calculate GHG emissions in ruminant production systems. This classification shows manure management in SSA livestock systems as shown in **Figure 3**, where the majority are drylot and pasture systems with limited options for integrated manure management.

In the case of pig and poultry, most of the animals are kept in backyard systems. For pigs, a wide range of manure storage systems have been applied as described by MacLeod et al. (2013), with commercial systems in SSA managing large fraction of the livestock manure in the drylot system (**Figure 3**). Backyard chickens, which are more common in SSA, are mostly free ranging and as a consequence, 50% of the manure is deposited randomly in the farmyard, with the other 50% deposited and applied on the field (MacLeod et al., 2013). For commercial chicken operations, the animals are confined most or all of the time and manure is stored either as deep litter (broilers) or in pits (layers). In broiler deep litter systems, manure is combined with the litter (commonly sawdust) and this combination is only removed after a complete batch of birds have been reared, typically 5–7 weeks in SSA. **Figure 4** shows a classification of manure management systems for poultry and pig in SSA, based on MacLeod et al. (2013).

Emissions from stored manure are strongly related to manure characteristics (e.g., liquid or solid manure), storage conditions (temperature, wind, humidity, etc.) as well as the storage duration of manure. Lorimor (2015) showed that ammonia loss is positively correlated with temperature, humidity, and wind speed, and that urine exposed to the air at 38°C lost 92% of its N in 7 weeks while it took 12 weeks to lose the same amount of N at 32.5°C. Rufino et al. (2007) found that manure covered with a plastic film and stored with roofing lost 20% of nitrogen compared to 55% nitrogen loss in manure that was stored in open heaps in Kenya. Another study in Western Kenya also found that manure stored in open pits had lower mass fractions of N and P than manure in heaps under roof and in open heaps (Tittonell et al., 2010). As a result, manure storage was identified as a key management variable affecting the efficiency of nutrient return to the soil (Snijders et al., 2008) with application of manure stored in covered pits increasing maize yields in Zimbabwe by 104% compared to farms that stored manure in open heaps (Mutiro and Murwira, 2003). It is therefore recommended to shade manure storage facilities as much as possible in order to reduce exposure to high temperatures and subsequent N losses, as well as limiting exposure to rainfall, and thus minimizing nutrient losses due to leaching. The long term storage of liquid manure in lagoons or deep pits produces more GHG (i.e., methane), compared to the storage of solid manure, due to the anaerobic conditions in liquid manure storages. Shorter storage periods also reduce N losses (Sumberg, 1998; Snijders et al., 2013) and are also recommended for SSA.

Manure Application Approach

In SSA, solid manure is commonly applied to agricultural fields in holes, in furrows or spread/broadcasted and incorporated. It is recommended that the manure be incorporated into the soil immediately after application, as it will retain more nutrients (in particular N) that will later be available to crops (Snijders et al., 2008). For example, 90% of N from liquid manure will be available to plants if it is incorporated within 8 h compared to only 40% N availability if incorporation is done after 5–7 days (Snijders et al., 2008). It is worth noting that in most cases in SSA, urine, and liquid manure are not often managed or applied to agricultural soils, but are left to (over) flow, and either end up in the soil or are washed into water bodies without any treatment (Teenstra et al., 2014).

Summary of Manure Management Approaches in SSA

Table 5 shows a summary of the most common manure management approaches in SSA bringing out their advantages and disadvantages. In summary, the use of manure as a fertilizer is generally beneficial to the soil and can improve crop yield. However, different strategies for manure management could lead to increased preservation of nutrients in manure, enhancing its use as a fertilizer.

CONCLUSIONS AND RECOMMENDATIONS

Manure is a great asset and if well-managed, could serve as an organic fertilizer and soil amendment that could restore degraded soils. However, recommended manure management approaches are not often followed in most sub-Saharan African countries. At the farm level, improvements to manure management is poor, often due to insufficient labor, lack of capital for investment, and a lack of knowledge. Manure is often stored without a proper

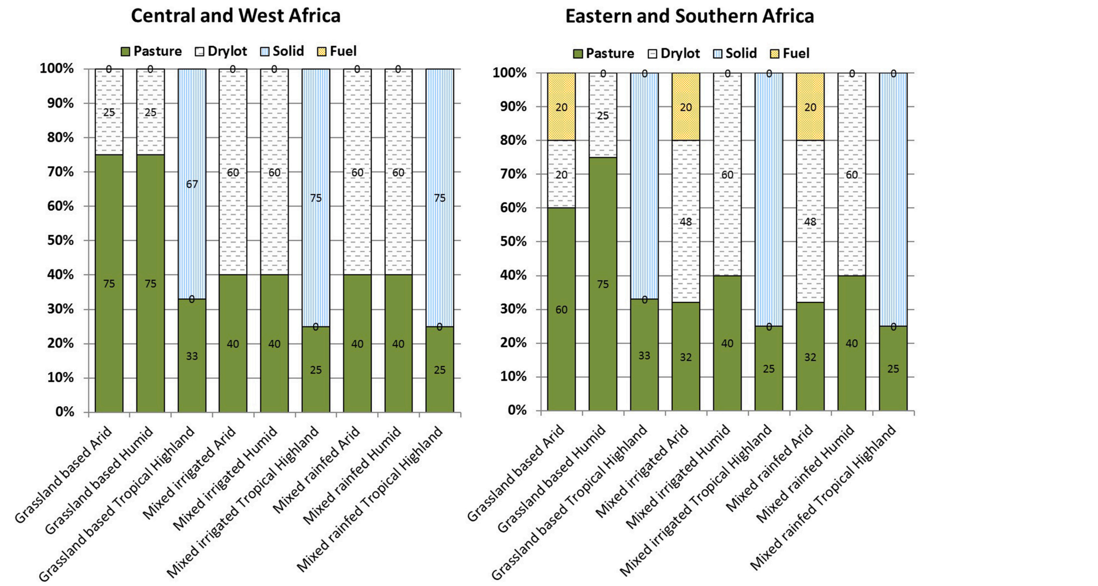

FIGURE 3 | Proportion of cattle production farmers practicing pasture, drylot, solid, and fuel manure management systems in sub-Saharan Africa—classified according to livestock production systems [Data to create this figure was obtained from Opio et al. (2013)].

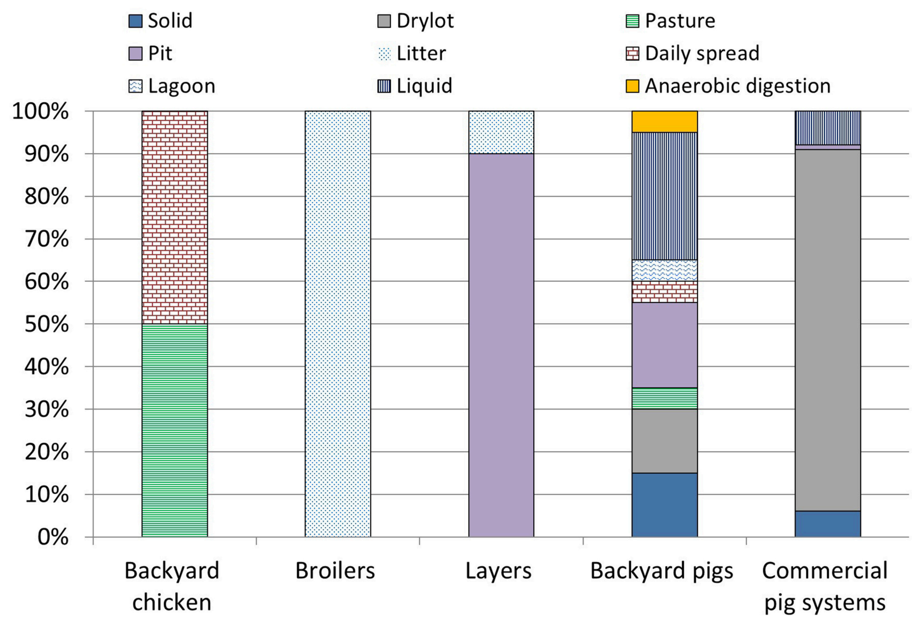

FIGURE 4 | Proportion of poultry and pig producers using various manure management systems in sub-Saharan Africa [Data to create this figure was obtained from MacLeod et al. (2013)].

impermeable floor and without a roof, leaving it susceptible to nutrient losses by rain and sun.

On the policy side, manure often is typically considered as a waste and government policies are strongly related to this view. This implies a greater focus on risk management and tends to limit use of manure rather than on the potential benefits of manure use as a fertilizer. Good manure management is also hindered by the fact that responsibilities for manure management are often spread over a number of ministries, without clear responsibilities and without good enforcement of rules.

Based on these findings we recommend that government policies should regard manure as a fertilizer and that they enact and enforce manure management policies that look to utilize this resource while still mitigating associated risks to human health and the environment. Government ministries also need to coordinate their policies on manure management to avoid inconsistencies and to clarify responsible parties for enforcement. It is necessary therefore, to organize sensitization programs to inform policy makers and other actors of the benefits of manure management, giving them a better chance to create a favorable environment for adoption of these practices, combined with adequate control and enforcement of such policies. Furthermore, capacity building programs including vocational trainings on manure management (especially for extension workers), exposure/exchange visits between farmers as well as a lead/model farm approach of extension would be of great importance. As well, farmers should explore options for improved forms of manure storage that reduce moisture in manure (e.g., composting) to make it easier to transport. Investors could also develop businesses of collecting manure from several farmers, composting and selling to large scale crop farmers. Finally, research programs are required to test and demonstrate the suitability and benefits of manure management in various regions to provide evidence on the benefits of good manure management practices.

AUTHOR CONTRIBUTIONS

ON, DP, JO, FdB, and TV contributed in writing the paper. ON structured and put the various parts together.

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