A review on health and environmental aspects of current manure management practices in pig production systems in Uganda

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Summary

Pig production in Uganda has increased over the past two decades and is projected to grow further due to the rising demand for pork. Pig production creates substantial amounts of manure and, if not handled well, can be a source of greenhouse gas (GHG) and ammonia (NH3) emissions, as well as nutrient leaching, resulting in acidification of rainwater and eutrophication of water bodies. Furthermore, pig manure can be both host and vector for diseases. To manage pig manure in a way that is both climate smart (i.e. helps to mitigate climate change) and sanitary, it is essential to have a detailed understanding of manure management systems that comprises animal feeds (diets), production systems, storage and handling, treatment, manure use and disposal.

This report presents the results of a literature review conducted to assess current pig production systems and associated manure management in Uganda, while also referring to literature from elsewhere where no information for Uganda was available. We specifically focused on the environmental (GHG emissions) and health (disease transmission) aspects of pig manure in Uganda. We found that pig production systems in Uganda can be categorized as either extensive, semi-intensive (tethering) and intensive. However, literature on pig manure management in Uganda is very scarce as most of the studies done in the country only characterized production systems but did not provide any information on how manure is managed. Across the country, pig manure is perceived as waste and its management and usefulness in improving soil fertility is not included in the Uganda fertilizer policy. However, given the growth of pig production, there is need to carry out studies to establish how manure is managed in different production systems, which can eventually guide the development of smart management practices that are environmentally friendly, assure high fertilizer quality and reduce animal and human health risks. Such studies could be instrumental in guiding policy advocacy and development in Uganda.

Background

There has been remarkable increase in global pig production in the past decade, especially in developing countries, to meet the rising demand from population growth and urbanization, as well as change in dietary preference towards more animal-based protein (Thornton 2010). Furthermore, pigs provide quicker returns than cattle because of their shorter lifecycle (Ndyomugyenyi and Kyasimire 2015) providing income to meet the immediate needs of farmers. Pig production also requires relatively little space compared to other livestock production systems, e.g. extensive cattle production, which makes it suitable for peri-urban settings (Thys et al. 2016).

The Uganda Bureau of Statistics noted a rapid increase in the number of pigs from 0.19 million in 1980 to 3.2 million in 2008 (MAAIF 2008). Eighteen percent of all households (1.1 million) own at least one pig, with the greatest pig population being located in the central districts (Wakiso, Masaka and Mukono), while the rest of the country is dominated by smallholder pig farmers (Ikwap et al. 2014; Anderson et al. 2016). However, the fast growth of pig production in Uganda poses several environmental, health and safety challenges. For example, waste from pig production such as manure produces a foul smell which can create conflict in urban and peri-urban pig production (Alvåsen 2007; Nantima et al. 2015). Furthermore, pig manure emits ammonia (NH3) that causes acid rain (Kruse and Bell 1987; Burns et al. 2016), and phosphorus leaching from manure results in eutrophication of water bodies (Daniel et al. 1998). Depending on the management system, pig manure can also be a substantial source of greenhouse gas (GHG) emissions (Herrero et al. 2016; Sakadevan and Nguyen 2017). Several studies have also observed that pig manure hosts diseases that can be transmitted to humans and other livestock (e.g. Bicudo and Goyal 2003; Ström et al. 2018; Venglovsky et al. 2018).

The present review aims to characterize current pig production systems in central Uganda with a focus on existing manure management and its environmental, health and safety issues. Targeted recommendations to improve manure management to reduce environmental and health burdens (“smart manure management”) will also be provided.

Greenhouse gas emissions from manure

Globally, the agriculture, forestry and other land uses (AFOLU) sector is the second largest contributor of GHG emissions with 23% (12 Gt CO_2eq yr^{-1}) of the total annual net anthropogenic GHG emissions (52 Gt CO_2eq yr^{-1}) for the period of 2007–2016 (IPCC 2019a, p.10). Concerning global livestock GHG emissions, cattle emissions dominate by far (54% from beef cattle and 17% from dairy cattle), followed by emissions from sheep (9%), buffalo (7%), pigs (5%) and goats (4%) (Caro et al. 2014). Of total GHG emissions from pig production globally, pig manure emissions represent 35.3% and include emissions from manure storage and processing (27.4%), and from applied and deposited manure (Macleod et al. 2013). With regards to climate change mitigation, the livestock sector is estimated to have a technical mitigation potential of up to 50% of the GHG emissions of the AFOLU sector, of which reduction of GHG emissions from manure is estimated at 0.01–0.08 GtCO_2eq yr^{-}1, mainly through reduction of nitrous oxide (N2O) emissions and nitrogen (N) losses from manure (Herrero et al. 2016).

However, these estimates have large uncertainties due to lack of accurate localized activity data (e.g. livestock numbers, feed availability and quality) from sub-Saharan Africa (SSA). Estimates from SSA are often based on default emission factors which have been largely generated in developed countries where conditions are quite different from SSA (e.g. different breeds, feeds and climatic conditions). In order to improve the reporting of national GHG inventories to fulfill the countries' nationally determined contributions (NDC) as agreed upon following the Paris Climate Agreement, a number of empirical studies have been carried out in East Africa to improve these estimates in Uganda (e.g. Kiggundu et al. 2019) and Kenya (e.g. Pelster et al. 2016; Goopy et al. 2018; Ndung'U et al. 2018; Zhu et al. 2018), but their focus has been mainly on cattle. Research that focuses on GHG emissions from pig production systems based in East Africa on in situ data remains scarce.

Pig production systems in Uganda

The primary factors that influence GHG emissions from manure include temperature, oxygen (O_2) availability (aeration), moisture and sources of nutrients. In addition, emissions are affected by manure type (livestock type/breed), feed type, manure texture (e.g. liquid slurry, solid, litter-based farmyard manure), manure storage type (e.g. solid heap, anaerobic lagoon, pit under confinement), and manure application to soils (e.g. top-dressed, injected, incorporated). These factors are largely influenced by the livestock production system (Robinson et al. 2011; Petersen et al. 2013). In Uganda, pig production systems can be separated into (i) extensive, (ii) semi-intensive (tethering) and (iii) intensive (FAO 2012; Kimbi et al. 2015; Nantima et al. 2015; Ndyomugyenyi and Kyasimire 2015; Pfeifer et al. 2015).

i. Extensive pig production system

In this system, animals are left to scavenge during the day and are confined either in pens, in other simple constructions, or tethered during the night. This system is mostly practiced in low input systems in rural areas where scavenging space is available (Thornton 2010; Dione et al. 2014), and is commonly applied during the dry season when feeds are scarce and expensive to buy (Dione et al. 2014). In this system, manure is deposited randomly on pastures while pigs scavenge during the day, making manure collection difficult (Pfeifer et al. 2015). Manure that is deposited in animal pens or fenced confinements overnight can be collected.

ii. Semi-intensive pig production system

This system is also referred to as tethering system, where pigs are usually tied with a rope under a tree or in a garden next to the home and left to scavenge within their movement radius. They are often supplemented with water, home refuse and crop residues. Once pastures are exhausted, pigs are moved to a different spot. This system is the most common system in rural areas especially in upcountry districts (Tororo, Hoima, Kayunga, Kamuli) that produce pigs for rural and urban markets (Dione et al. 2014; Nalubwama et al. 2014; Nantima et al. 2015; Pfeifer et al. 2015; Roesel et al. 2017). In this system, manure is produced in a restricted area and can be managed more easily as compared to a free-range system. A focus group discussion in Hoima district revealed that when farmers periodically move animals once the pasture is exhausted, they spread and incorporate the manure into the soil as fertilizer (Pfeifer et al. 2015).

iii. Intensive pig production system

This is a high-investment system where animals are totally confined and provided with shelter, food and water. This system is used where there is not enough land to practice free-range or tethering and is common in urban areas and among rural farmers who produce intensively for the urban market (Dione et al. 2014; Pfeifer et al. 2015). Herd sizes in this system are often large (50–300 animals) compared to free-range or tethering systems (one to five animals) (Okello et al. 2015; Nabikyu and Kugonza 2016). Many farmers in intensive production systems keep improved pig breeds, which are more susceptible to tropical diseases (Dione et al. 2014; Pfeifer et al. 2015). Pigs in intensive systems are usually fed on nutrient- and energy-rich commercial feeds such as concentrates, maize and rice brans, and waste. In these systems, animals are housed fulltime, in most cases in barns with raised or concrete floors that can facilitate manure collection, which is primarily done for hygiene purposes (Dione et al. 2014). Key stakeholders in Hoima district reported that in this system, manure is mostly washed into pits or stacked into piles and is often not used as fertilizer (Pfeifer et al. 2015). Another study in Kampala found that 48% of farmers apply manure from their pig units in their gardens, 30 % heap the manure and dispose of it in garbage dumping areas or other unspecified areas after a certain storage period (ranging from one week to 3 months), and 10 % of the pig farmers dispose the manure daily in dumping sites or in other unspecified areas (Alvåsen 2007).

Pig manure characteristics

Pig manure consists of faeces and urine and is rich in carbon (C), nitrogen (N, primarily urea from urine and organic N from faeces), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), and micro-elements such as iron (Fe), manganese (Mn), zinc (Zn), cobalt (Co) and copper (Cu) (Okoli et al. 2019). Pig manure generally has higher N concentrations compared to manure from ruminants such as cattle that feed on roughages (Table 1). Consequently, the carbon: nitrogen ratio (C:N ratio) of pig manure is lower than cattle manure, indicating a higher fertilizer value and better degradability. For this reason, pig manure has been reported to yield more biogas compared to cattle manure (Fantozzi and Buratti 2009; Li et al. 2020).

Table 1: Examples of nitrogen concentration and C:N ratio of pig versus cattle manure in sub-Sahara Africa

Source	Nigeria (Okoli et al. 2019)	Uganda (Alvåsen 2007)		Zimbabwe (Nyamangara et al. 2010)	
Manure type	Fresh pig manure	Fresh pig manure	Fresh cattle manure	Fresh pig manure	Fresh cattle manure
Nitrogen (% DM)	2.25	3.5	1	3.1	0.8
C:N ratio	7.8	11.8	31.8	4.3	14.3

The concentration of nutrients in faecal matter and urine depends largely on the animal's diet. For instance, faecal and urinary N excretion from pigs has been found to increase with increasing dietary crude protein (CP) intake (Portejoie et al. 2004; Liu et al. 2018). Furthermore, Liu et al. (2018) observed a linear relationship between faecal P excretion and dietary P intake as long as the Ca:P ratio remained constant. High levels of Ca in diets reduce P digestibility through formation of an insoluble Ca-P complex, and thus most of the dietary P intake is excreted (Selle et al. 2009). The amount of N and P excreted in faecal matter and urine is further determined by several other factors such as animal growth stage, feed formulation, pig species and complex interactions between these factors. Dourmad et al. (1999) observed that mean N retention in pigs differed among growing stages with 23% dietary N being retained by sows, 34% by growing pigs and 48% by weaners. Furthermore, partitioning of N between faecal and urinary excreta is also influenced by diet composition (Nguyen et al. 2019) with diets high in dietary fibre (cellulose and hemicelluloses) leading to more allocation of N to faeces compared to urine (Prapaspongsa et al. 2009). Since dietary fibre is the main factor for N partitioning between faeces and urine (Jørgensen et al. 2013), dietary manipulation towards higher fibre intake can be used to shift the allocation from urinary N (mostly urea) towards faecal N (mostly organic N), which can help to reduce NH3 emissions from pig manure (Galassi et al. 2010). Additionally, diet composition also affects the pH of faeces, urine and their mixture (Canh et al. 1997). Both N partitioning and pH modification affect NH3 and GHG emissions from manure. As mentioned before, NH3 emissions can cause acid rain and lead to soil acidification (Guthrie et al. 2018). Furthermore, NH_3 reacts with acids in the atmosphere, which leads to formation of ammonium aerosols—fine particulate matter (aerodynamic diameter <2.5 μm) that poses a health hazard (Aneja et al. 2008). Given that pig production in Uganda is growing rapidly, especially in peri-urban and urban areas where commercial nutrient-rich feeds are used (MAAIF 2008), this could exacerbate environmental pollution unless mitigation measures are put in place.

Pig manure and health issues

Pig manure contains microorganisms, protozoa and viruses that may pose a risk to human and animal health. A recent review by Alegbeleye et al. (2018) highlighted public health diseases that can be transmitted through raw or poorly treated animal manure, including *Escherichia coli* O157:H7, *Salmonella* spp., *Listeria monocytogenes*, Campylobacter spp., porcine enteroviruses, bovine coronavirus, bovine virus, diarrhea, *Cryptosporidium parvum* and Giardia. In addition, contaminated soils can act as a habitant for pathogens with some persisting for months or even years in the soil (Alegbeleye et al. 2018). In Uganda, it is common practice to spread untreated manure on the soil, which represents high risk of pathogen distribution in the environment. Highly contagious and pathogenic viral diseases such as foot and mouth disease, classical swine fever and Aujeszky's disease may spread through animal effluents into waterways and when one farm is infected, other downstream farms may be exposed to considerable risk of infection (Johansson et al. 2005). Pathogens in untreated manure can also be transmitted to other livestock, humans or food by vectors such as flies, rodents and birds (von Holy et al. 2006) This is a common problem in systems where manure is not collected routinely. Furthermore, use of antibiotics to control bacterial infections is increasing in Ugandan pig production which poses the risk of development of antibiotic-resistant bacteria in pigs, which may further lead to emergence of antibiotic resistance in human and other livestock pathogens (Kang et al. 2018; Xie et al. 2018). It is estimated that 70–90% of antibiotics administered to pigs are discharged via faeces and urine in unchanged or active metabolite form (Dolliver et al. 2008). However, treatment of resistant strains is expensive, often more toxic for the host, and in general difficult to treat if suitable drugs are not available.

Manure handling, storage and treatment options to reduce GHG emissions and improve health and safety

GHGs from manure are produced via different microbial pathways. These processes are influenced by manure characteristics (e.g. water content, O_2 level, nutrient concentration) and environmental parameters (e.g. temperature, rainfall). N_2O is mainly produced through nitrification and denitrification processes, although other pathways such as dissimilatory nitrate reduction to ammonium (DNRA) have been reported (Butterbach-Bahl et al. 2013). Nitrification involves the microbially mediated transformation of ammonium (NH_4+) to nitrate (NO_3-) by ammonium- and nitrite-oxidizing bacteria and archaea under aerobic conditions (i.e. presence of O_2). On the other hand, denitrification is a (facultatively) anaerobic process (i.e. requires low levels or absence of O_2) and involves reduction of NO_3- and nitrite (NO_2) to N_2O and N_2 gas. In addition to low O_2 levels, denitrifier microorganisms are heterotrophic and require C as a source of energy. Nitrification and denitrification are closely linked, and N_2O emissions have been reported to be highest under intermediate water content, when both aerobic and anaerobic microsites exist in proximity (Butterbach-Bahl et al. 2013). Furthermore, N_2O formation responds to temperature, with the optimum temperature being between 20 and 35°C, which leads to high emissions in tropical and subtropical regions.

Contrary to N_2O formation, CH_4 production (methanogenesis) is a strictly anaerobic process that requires absence of O_2 and the presence of C substrates from faecal matter or bedding material that can be reduced to CH_4 (Serrano-Silva et al. 2014). Similar to N_2O formation, CH_4 production is controlled by temperature, moisture and availability of organic substrates. All these factors—moisture, temperature and C availability—are in turn affected by the type of manure management (i.e. handling, treatment and storage conditions) (Petersen et al. 2013). Pig manure is handled as solid, semi-solid/slurry or liquid depending on the type of housing and production system. Generally, solid manure (including deposited manure on pastures) produces less CH_4 and more N_2O, while manure handled in slurry or liquid form produces more CH_4 but less N_2O (Chadwick et al. 2011).

Manure storage

Manure storage GHG emissions represent 10–25% of total emissions from the livestock sector (Gerber et al. 2013; Serrano-Silva et al. 2014). In pig production systems, manure storage is the greatest source of GHG emissions (69%) since pigs are monogastric animals and do not produce enteric CH_4 like ruminants (cattle, sheep and goats). Emissions of GHGs and NH3 during storage are influenced by water content of manure (solid, slurry, or liquid), environmental factors (e.g. temperature, humidity and wind), and the storage duration. In smallholder and extensive systems in SSA, manure is mainly stored in solid form (Petersen et al. 2013). Manure that is dropped when animals are tethered or confined is collected in heaps and applied to fields after varying durations of storage times, or disposed of as waste (Ndambi et al. 2019). Manure from free-roaming animals is not usually collected; it's left where it is deposited. However, manure that is left in open fields without management is prone to nutrient loss through leaching and volatilization, thereby compromising fertilizer value and promoting GHG emissions. Furthermore, unmanaged manure is a liability as it can promote diseases.

A study on urban and peri-urban livestock farming from Tanzania observed that most of the respondents stored manure in heaps before disposal, while only a few farmers directly spread the manure in the surrounding environment (Lupindu et al. 2012). Similar observations were made in Hoima, Uganda (Alvåsen 2007). Heaped solid manure primarily emits N_2O given the conducive environment of partial aerobic and anaerobic state that promotes nitrification and denitrification, but if the heap is big enough to maintain a moist, anaerobic core, it can also promote

CH_4 emissions (Chadwick et al. 2011). Therefore, management practices that increase aeration, such as regular turning to promote O_2 supply, can help reduce N_2O and CH_4 emissions from manure (Petersen et al. 2013).

In the intensive pig production systems of central Uganda, some farmers house their animals on concrete floors which are flushed with water for cleaning. Pig manure is collected after flushing and stored in liquid/slurry form (Alvåsen 2007; Pfeifer et al. 2015). Manure stored as liquid/slurry represents an anaerobic environment, which promotes CH_4 emissions. Since temperature is a driving factor for CH_4 production (Sommer et al. 2007; Elsgaard et al. 2016; Moset et al. 2019), CH_4 production from slurry lagoons is promoted under subtropical conditions. While CH_4 emissions can be decreased via a reduction of storage temperature (Borhan et al. 2012), temperature manipulation to mitigate CH_4 emissions from liquid/slurry manure in SSA might be challenging. Other than temperature, factors such as microbial community composition, manure organic matter quality content and pH also affect CH_4 production from liquid/slurry manure (Elsgaard et al. 2016). However, these factors are difficult to manipulate in smallholder settings and reducing CH4 emissions from slurry/liquid manure storage in Uganda might currently be challenging.

Manure composting

Composting is a widely recognized biological process of managing organic waste. Composting is the microbially mediated bio oxidation of organic matter into a potentially safe, nutrient-stable and sanitary fertilizer. During aerobic composting, temperatures can rise to up to 80°C, a temperature that eliminates most pathogens (Riddech et al. 2002). A number of studies (e.g. Tiquia et al. 1998; Mc Carthy et al. 2011; Gurtler et al. 2018) have reported elimination of pathogens such as Salmonella, Coliforms and faecal Streptococci in contaminated manure after aerobic composting. Moreover, it was noted that antibiotics are degraded during compositing (Dolliver et al. 2008; Ramaswamy et al. 2010; Ho et al. 2013; Massé et al. 2014), thus averting potential environmental contamination.

Composting is seen not only as an environmentally acceptable method of waste treatment, but also as one of the more efficient methods of waste disposal that enables recycling of organic matter (FAO 2003). During composting, stable N compounds are formed in the microbial decomposer biomass; these compounds are less susceptible to losses via volatilization, denitrification and leaching. Therefore, the stable N in composted manure has a smaller environmental footprint and is a better source of nutrients when applied to soil as fertilizer for crop production. Furthermore, the partially humified product of composting is relatively resilient to decomposition, therefore compost C is retained in the soil for a longer period (Bernal et al. 2009). Even though during the composting process CO_2 is emitted, the global warming potential of CO_2 from manure is considered to be carbon neutral because it originates from CO_2 that had been fixed by plants during photosynthesis and is not of fossil origin (IPCC 2006, 2019b). Finally, if composted manure is used instead of mineral fertilizer, it will reduce the environmental footprint of pig farming by avoiding GHG emissions associated with fertilizer production and use (Paul et al. 2001).

Biogas production

Biogas is a gas mixture consisting primarily of CO2 and CH4, which is produced via microbial digestion of organic materials in an anaerobic environment. Biogas production with pig manure is a suitable method for the treatment of this organic waste, yielding biogas as a useful byproduct (e.g. as cooking gas). The digested manure can be used as soil conditioner and nutrient-rich liquid fertilizer that is valuable for crop production. In Uganda, the biogas production technology was introduced over 50 years ago and since then there has been a lot of effort from nongovernmental organizations and the government to promote this technology. However, the adoption has been low primarily attributed to lack of capital for the investment (Walekhwa et al. 2009). Even with initiatives to alleviate financial constraints, it has been noted that those who adopted the biogas technology often abandoned it after a short period (Nabuuma and Okure 2006). Lwiza et al. (2017) explored the drivers of discontinuation of biogas use and noted that among others, failure to sustain livestock production, reduced availability of family labor and inability of households to repair biogas digesters after malfunctioning were the main causes for abandoning this technology. However, digestion and fermentation of manure in biogas digesters can help reduce pathogen survival in manure, especially in conjunction with post-digestion composting of bio-slurry to promote further pathogen die-off, which could make this technique well suited for climate-smart and safe pig manure management in SSA (Avery et al. 2014).

Vermicomposting

Vermicomposting is a process by which organic waste such as pig manure are fed to worms (e.g. earthworms and larvae of the Black Soldier Fly [*Hermetia illucens*]), yielding two products—the worm biomass (30–60% protein content) which can be used as livestock feed especially for pigs, chicken and fish (Oonincx et al. 2015); and a humus-like material rich in nutrients that can be used as organic fertilizer (Semiyaga et al. 2015). The worms can reduce odorous volatile substances by up to 100% (Gajalakshmi and Abbasi 2004; Oonincx et al. 2015; Miranda et al. 2019). Komakech et al. (2015) assessed global warming and eutrophication potentials of composting and vermicomposting as compared to daily manure dumping on landfills in Kampala, Uganda, and found that the global warming potential of composting (5.1 CO_2-eq ton^{-1}) and vermicomposting (17.8 CO_2-eq ton^{-1}) was significantly lower than that of dumped manure (56.6 kg CO_2-eq ton^{-1}). Vermicomposting also had the lowest eutrophication potential. In Uganda, vermicomposting is taking shape as a potential environment and health friendly waste management method in urban settings. A case study in Kampala tested small-scale vermicomposting of cattle manure with food waste using the earthworm species *Eudrilus eugeniae* and found that vermicomposting successfully eliminated *Salmonell*a spp. contamination from the organic waste (Lalander et al. 2015). However, vermicomposting did not completely reduce other pathogens (e.g. Enterococcus spp., bacteriophage X174 or *Ascaris suum ova*) (Lalander et al. 2013), which is why an additional sanitation step like ammonia treatment was suggested (Vinnerås 2007). A large-scale company—ProTeen Marula Agribusiness, www.weareproteen.com—recently signed a memorandum of understanding with the Kampala City Council Authority to establish a vermicomposting plant at the main landfill site in Kampala. The company has been carrying out pilot vermicomposting trials on urban organic waste using Black Soldier Fly larvae. Adoption of this technique by smallholder farmers is still low. However, vermicomposting has been reported to be a viable business for smallholder farmers with potential return to investment of over 200 % (Lalander et al. 2015). More research is necessary to identify needs of farmers and consumers and constraints concerning use and consumption of products from livestock fed vermicomposted pig manure.

Conclusion

Little attention has been given to pig manure management in Uganda so far. While a few papers have been published on pig production systems in Uganda, data on current manure management practices were rarely collected and presented. In Uganda, pig manure is mostly regarded as waste, of little importance and does not require management. However, given the rapid growth of Ugandan pig production, climate-smart and sanitary solutions for pig manure management are urgently needed to ensure sustainable and safe development of the sector. If managed correctly, pig manure has great potential to improve soil fertility. Proper management can also help mitigate GHG emissions, provide additional income and reduce health risks related to the spread of disease or development of antibiotic resistance. Composting, biogas and vermicomposting are promising manure management solutions for both smallholder and industrial pig producers in Uganda.

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