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Research article

Environmental impact from vermicomposting of organic waste in Kampala, Uganda

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A B S T R A C T

Urban animal farming is becoming increasingly important in feeding the growing population of many sub-Saharan African cities. However, management of the animal manure generated is proving to be challenging due to space restrictions. Vermicomposting is one of the methods proposed to address this challenge. This study investigated the environmental performance of the vermicompost system by measuring the gaseous emissions generated from the system. In addition, the vermicompost system was compared with other manure management systems currently in use, using life cycle assessment (LCA) methodology. The emissions factors for the vermicompost system were found to be 10.8, 62.3 and 12.8 g/Megagram biowaste for methane, nitrous oxide and ammonia, respectively. LCA showed satisfactory performance of vermicomposting in terms of global warming and eutrophication potential, although if the vermicompost generated is dumped, this could lead to increased eutrophication. However, this is still much lower than the eutrophication caused by open dumping of untreated manure.

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1. Introduction

Economic development and the improvements in lifestyles witnessed in most low- and middle-income (LAMI) countries are being accompanied by generation of increased amounts of waste (Goorhuis, 2014). Management of municipal solid waste (MSW), especially organic waste, is a challenge with which authorities are grappling in many towns and cities in sub-Saharan Africa (SSA). According to Hoornweg and Bhada-Tata (2012), it is arguably the most important municipal service provided by municipal authorities and is usually a city's single largest budgetary item. It mainly involves the collection of waste and its transportation to landfill (Cheremisinoff, 2003; Zhu et al., 2008), with most of the budget being used for waste collection and the salaries of waste sweepers (Zhu et al., 2008). However in many SSA cities, less than half the waste generated is collected and taken to landfill (OAG, 2010; Ofori-Boateng et al., 2013). Landfilling, like other end-of-pipe treatment methods and disposal methods, not only imposes high operating and capital costs, but is also associated with long-term liabilities (Cheremisinoff, 2003). These include acting as a source of leachate and other contaminants that can pollute underground aquifers and surface water. Landfills are also recognised as a major source of anthropogenic methane emissions and an important contributor to global warming, accounting for up to 19% of methane emissions in the world (Kumar et al., 2004). In addition, high land prices as a result of rising populations and incomes in many cities (Idris et al., 2004) have greatly reduced the economic attractiveness of landfilling, thus fostering initiatives to divert waste prior to landfilling. Finally, wastes also contain resources that could meet the demand for energy and vital plant nutrients (Komakech et al., 2014b) and all these resources are lost when the wastes are landfilled.

Because of the pronounced disadvantages of landfill, countries worldwide have introduced various measures to limit its use. In many high-income countries, only inert waste is accepted in landfill and other waste is subjected to different waste treatment methods, such as composting, recycling and incineration with energy recovery (Geng et al., 2010). In LAMI countries, measures to reduce

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the waste going to landfill mainly involve value addition to the dominant organic waste stream. These include anaerobic digestion (AD), composting and incineration with energy recovery, with composting being the most prominent (Hoornweg and Bhada-Tata, 2012; Zurbrügg et al., 2005). However these efforts have not been particularly successful (Oteng-Ababio et al., 2013; Parawira, 2009). In the case of composting, for instance, one of the major reasons for its failure is the lack of a ready market for the fertiliser produced (Ngoc and Schnitzer, 2009), thus showing how unappreciative farmers are of this organic waste value chain. Compared with chemical fertilisers, bio-fertilisers have the disadvantage of diluted nutrients. The most used fertiliser globally, urea, contains 46% nitrogen, whereas manure contains only 0.5% and the nitrogen is also less-plant available than that in urea. This results in a major difference in the field work required to apply 1 kg of nitrogen (2.2 kg urea versus 200 kg of compost). For AD, according to Parawira (2009), economic, political and technical factors present the major challenges to its development. There is therefore an urgent need to investigate the attractiveness of other organic waste value addition technologies.

One such technology is vermicomposting, which is the process by which worms are used to convert organic wastes into a humus-like substance called vermicompost (Munroe, 2007). Another by-product of this process is the worm biomass, which can be used a suitable source of animal protein (Lalander et al., 2015). In previous experiments carried out in Kampala on non-optimised vermicompost reactors, it was established that vermicomposting performs well, with a material reduction rate of 45.9%, a waste-to-biomass conversion rate of 3.5% and a return on investment of 275% when treating 450 kg cow manure. However, the experiments also established that the vermicompost reactors were associated with poor performance in terms of pathogen reduction (Lalander et al., 2015). Data on greenhouse gases (GHG) and other emissions from vermicompost reactors in SSA are not readily available. Thus the objective of the present study was to measure emissions of GHG and other emissions from vermicomposting of mainly animal wastes in Kampala, Uganda, and to compare the results to emissions from waste management practices currently in use for managing such waste in Uganda, namely open dumping and storage for use as fertiliser. The overall aim was to test whether adoption of vermicomposting of waste could provide a reduction in GHG and other emissions associated with current waste management. In addition, a life cycle assessment (LCA) and economic comparison studies were performed to compare the environmental and economic performance, respectively, of vermicompost and of other manure management systems.

2. Materials and methods

Direct emissions were measured from small-scale vermicompost reactor units set up at Makerere University Agricultural Research Institute Kabanyolo (MUARIK). The LCA methodology was used to perform the environmental comparison and evaluate the environmental improvement of the vermicompost technology and the current baseline technologies used to handle the waste. The methods used are discussed further in the following section.

2.1. Study area

The vermicompost units were established in Makerere University Agricultural Institute Kabanyolo (MUARIK), which is located about 21 km north of Kampala city at coordinates 0°27′03.0″ N and 32°36′42.0″ E (Komakech et al., 2015b). The area receives about 1300 mm of rainfall per annum, while its temperature varies between 20 and 28 °C. MUARIK has a dairy farm, which was the source of the animal manure used in the vermicompost reactors. The operation and other details of the vermicompost reactor have been described previously (Lalander et al., 2015). The reactors were made of hardwood pallets (three in number), measuring 1 m by 1 m by 0.8 m, each filled with manure. Indigenous earthworms (species *E. eugeniae*) picked from manure piles were used. Worm density at the time of measurement was about 4 kg/m^2.

2.2. Measurements of emissions

The vermicompost units were wrapped in high-density polyethene film and sealed with cellotape to minimise gaseous losses. The gas in each of the three vermicompost reactors was sampled on four occasions in April 2014, details of which are shown in Table 1. At each sampling, gas was collected from the sealed vermicompost using four 60-mL gas syringes, which were then tightly sealed, suitably packaged for transportation as shown in Fig. 1 and taken to the government analytical laboratory for measurement of nitrous oxide, ammonia and methane. Nitrous oxide was analysed using a gas chromatograph (PerkinElmer Clarus 680 with electron capture detector and temperature range 100–450 °C), following procedures specified by Ermolaev et al. (2014), while ammonia was measured using a Gas Alert Max Xt II multigas detector (BW Technologies, Schaumburg, Illinois, USA) fitted with an ammonia sensor. Methane was measured using a Crowcon Triple Plus IR mode gas detector (Bristol, UK). The data collected were analysed using two-way ANOVA and Tukey tests in R statistical software to check for differences in gas composition. The procedures used were as specified by Venables et al. (2012). However, the airflow velocity from the vermicompost reactor could not be measured because the flow rates were too low. To overcome this problem, emissions factors were estimated based on the dynamic respiration index (DRI) as proposed by Lleó et al. (2013). The DRI value used was determined from data presented by Lalander et al. (2015).

2.3. LCA methodology

The LCA methodology used to perform the environmental comparison between vermicompost technology and the current methods being used to handle the waste is explained in more detail in the following sub-sections.

2.3.1. Goal, scope and functional unit

The goal of the study was to evaluate the vermicompost method of treating animal manure (Scenario Ib) in Kampala in terms of the environmental impacts (global warming potential (GWP) and eutrophication potential). This was compared with the current ubiquitous practice of dumping animal manure (Scenario Ic: Baseline condition) or using it as fertiliser in gardens (Scenario Ia) (Komakech et al., 2014a). The LCA performed also sought to identify

Table 1
Sequence of measurement of emissions.

Time	Activity
8.00	Cover vermicompost units with plastic
9.00	Sample gas in the units and uncover units[a]
10.00	Cover vermicompost units with plastic
11.00	Sample gas in the units and uncover units
12.00	Feed the units
13.00	Cover vermicompost units with plastic
14.00	Sample gas in the units and uncover units
15.00	Leave units uncovered
16.00	Cover vermicompost units with plastic
17.00	Sample gas in the units and uncover units

[a] To ensure that the vermicompost units were not starved of oxygen supply.

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