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Contribution of Composting and Surface Decomposition of Farm Waste to the Mitigation of CO_2 and CH_4 from Selected Farm Wastes in Masaka and Lyantonde Districts

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Abstract

Agriculture in Uganda is the leading sector, employing over 85% of the entire population, with 68% of farmers struggling as smallholder farmers. Thus, agriculture is dominated by smallholder farmers. Available reports emphasize the contribution of the agricultural sector to greenhouse gas emissions (GHG), such as carbon dioxide (CO_2) and methane (CH_4). During the course of farming, smallholder farmers make many attempts to either benefit from the farm wastes generated or to get rid of them directly or indirectly. Thus, we realize some go for composting, which is intentional, while others opt for surface decomposition, which is seen as the default approach. Whatever option of waste management is chosen, there is efficacy for the method. The type of system waste component and waste management practice greatly contribute to GHG emissions, such as CO_2 and CH_4. The efficacy of each method varies considerably in terms of mitigating GHG emissions. This study considered farm wastes (bean trash, maize trash, banana trash, cattle slurry, goat slurry, and pig slurry) commonly produced by smallholder farmers in two farming systems of Masaka and Lyantonde Districts to: estimate the relative carbon dioxide and methane emissions of each selected farm waste component in different farming systems (arable and mixed, represented by Masaka and Lyantonde Districts, respectively), and estimate the relative carbon dioxide and methane emissions of selected aggregated farm waste. Using a gas analyzer F-950 (three-gas analyzer), we determined carbon dioxide and oxygen from airtight containers in which individual farm wastes/aggregated farm wastes were contained. Basing our calculations on the gas laws, we used a formula $V_2 = \frac{P_{1V_1}}{P_2}$ to compute and obtain corresponding methane values. Results revealed that composting beans from the arable farming system captured the highest volume of 784.3 ppm of CO_2 and 978.7 ppm of CH_4 at 3000 cm^{-1}. In the mixed farming system, pig slurry produced the highest volume of CH_4 (556 ppm), while maize produced more CO_2 volumes under composting (602 ppm). The mixed farming system produces the highest volume of CO_2 and CH_4 emissions compared to the arable farming system.

Keywords

Greenhouse Gas Emissions, Carbon Dioxide, Methane, Smallholder Farmers, Composting, Surface Decomposition, Farm Wastes

1. Introduction

Globally, IPCC (2019) estimated that 23% of total anthropogenic greenhouse gas emissions in 2007-2016 were derived from agriculture, forestry, and other land use [1]. These activities accounted for around 13% of CO_2, 44% of methane (CH_4) [2], and Uganda climate change action report (2016) reported that emissions from agricultural wastes had an average annual increase of 4%. Among the activities that drive agriculture sector GHG emissions are livestock production, inefficient crop and animal waste management [3]. This justifies the anthropogenic global warming theory, which informs this study on the grounds that the emissions generated through poor waste management are anthropogenic and will continue to rise unless intercepted [4]. The Waste Management Theory (WMT) has also been adopted because of its knowledge about waste and waste management.

The type of system waste component and waste management practice greatly contribute to GHG emissions, such as CO_2 and CH_4. The quantities of waste components vary considerably across farming systems and management systems. In this study, relative emissions captured imply the net variance in volumes of greenhouse gases recorded per volume of farm waste, either composted or surface deposited. Determining relative GHG emissions from the selected farm waste component was conducted in a laboratory environment because of limited mobility of the required equipment and COVID-19 restrictions.

2. Methodology

2.1. Procedures to Determine GHG Emissions from Selected Farm Wastes by Smallholder Farming Systems (Arable and Mixed Farming Systems)

Individual farm wastes (bean trash, maize trash, banana trash, cattle slurry, goat slurry, and pig slurry) commonly produced by smallholder farmers in two farming systems of Masaka and Lyantonde Districts were composted in containers, each with a capacity of 5000 cc at room temperature. The contents were turned periodically to maintain adequate aeration. This compost was prepared under a shade to minimize nutrient losses through evaporation.

In another experiment, containers each with a capacity of 5000 cc were filled up to 3000 cm^3, leaving a 40% headspace with similar wastes, and were located at one open end of the lab and exposed to sunlight all day.

In a control experiment, pure soil was put in the containers instead of farm wastes and either composted or surface deposited under the same laboratory conditions as the test samples. Procedures similar to those followed when collecting GHG emissions from compost and surface-deposited wastes described earlier will be followed in both farming systems.

Using a gas analyzer F-950 (three gas analyzer), we determined Carbon dioxide and oxygen from airtight containers in which individual farm wastes/aggregated farm wastes were contained. Based on the gas laws, we used a formula $V_2 = \frac{P_{1V_1}}{P_2}$ to compute and obtain corresponding methane values. We calibrated the gas analyzer first. We inserted the gas sampling probe into the rubber cup of each container. The gas meter displayed the corresponding quantity for each recordable gas on the screen. We recorded each value in an Excel sheet. We carried out the experiment for 30 days and continued recording every other two days.

2.2. Procedures to Determine GHG Emissions from Aggregated System Farm Wastes by Smallholder Farming Systems (Arable and Mixed Farming Systems)

Three different types of compost were formulated.

1) C1: Only crop residues that are reported to be commonly used ingredients either in composting or surface deposition by arable smallholder farmers.

2) C2: Only animal wastes that are reported to be commonly used ingredients, either in composting or surface deposition by mixed smallholder farmers.

3) C3: Both crop and animal wastes are reported to be commonly used ingredients, either in composting or surface deposition by mixed smallholder farmers.

The above-named mixtures of wastes were composted in containers, each with a capacity of 5000 cc, filled up to 3000 cm^3, leaving a 40% headspace. These were turned periodically to maintain adequate aeration. This compost was prepared under a shade to minimize nutrient losses through evaporation.

In another experiment, containers each with a capacity of 5000 cc were filled up to 3000 cm^3, leaving a 40% headspace, with similar wastes and located at one open end of the lab and exposed to sunlight all day. Three waste combinations were labeled as follows:

1) S1: Only crop residues that are reported to be commonly used ingredients, either in composting or surface deposition by arable smallholder farmers.

2) S2: Only animal wastes that are reported to be commonly used ingredients, either in composting or surface deposition, by mixed smallholder farmers.

3) S3: Both crop and animal wastes are reported to be commonly used ingredients either in composting or surface deposition by mixed smallholder farmers. *Adopted from* [5].

In a control experiment, pure soil was put in the containers instead of farm wastes and either composted or surface deposited under the same laboratory conditions as the test samples. Procedures similar to those followed when collecting GHG emissions from compost and surface-deposited wastes described earlier will be followed in both farming systems.

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2.3. The Study Area and Design

Masaka District is bordered by Bukomansimbi District to the north-west, Kalungu District to the north, Kalangala District to the east and south, Rakai District to the south-west, and Lwengo District to the west. The coordinates of the district are 00 30S, 31 45E.

Lyantonde is located in the Southwestern region of Uganda, lying between latitude 0˚S and 0.5˚S, and longitude 31.1˚E and 31.3˚E. Lyantonde borders Rakai District in the south, Masaka in the east, Kiruhura in the west, and Sembabule in the northeast.

Masaka District is located in the arable farming system, while Lyantonde District is located in the mixed farming system. Each district therefore represents a corresponding farming system. All samples were collected from these two farming systems.

We used quantitative methods to determine the relative GHG emissions of each system waste component and the aggregated farm wastes from biodegradable wastes of different smallholder farming systems [7]-[9].

Each waste category was weighed and recorded prior to the start of composting and GHG analysis [10]. Both the individual waste category and the aggregated waste category were grouped into two testing groups. One testing group was composted and the second group was surface decomposed.

Contents in the testing group were composted/surface decomposed in containers, each with a capacity of 5000 cc. Farm wastes were filled up to 3000 cm^3, leaving a 40% headspace. The contents were turned periodically to maintain adequate aeration.

To collect GHG emissions, a closed chamber technique was used as proposed and used by [11] [12], as described by [13] with some modifications. This method was used because it was easy, cheap, and did not require sophisticated instruments. Its versatility, design, and application procedures can be adapted to a wide range of situations.

2.4. Sampling Procedure

Total population sampling was used. This is a type of purposive sampling where the whole population of farm wastes was studied. It was the most appropriate procedure for the population of 68 samples, which were manageable in size (48 individual waste samples, 16 aggregated waste samples, and 4 controls were sampled from both farming systems).

All waste materials involved in this study were sampled. The sampling interval was 48 hours or the chamber closure duration. This increased precision and saved on the cost of setting up experiments that would not be sampled in case sampling was randomized.

2.5. Data Collection

To collect GHG emissions, a closed chamber technique was used as proposed and used by [10] [11] [14] as described by [13] with some modifications. This method was appropriate because it was easy, cheap, and did not require sophisticated instruments. Its versatility, design, and application procedures can be adapted to a wide range of situations.

Using a gas analyzer F-950 (three gas analyzer), we determined Carbon dioxide and oxygen from airtight containers in which individual farm wastes/aggregated farm wastes were contained. Based on the gas laws, we used a formula $V_2 = \frac{P_{1V_1}}{P_2}$ to compute and obtain corresponding methane values [6]. We calibrated the gas analyzer first. We inserted the gas sampling probe into the rubber cup of each container. The gas meter displayed the corresponding quantity for each recordable gas on the screen. We recorded each value in an Excel sheet. We carried out the experiment for 30 days, and we continued recording every other two days.

2.6. Data Analysis

2.6.1. General

In this study, preliminary data were analyzed in Excel using descriptive statistics. Thus, frequency tables and charts were developed to provide simple summaries about the sample and related measurements. The quantitative data were then analyzed in SPSS, starting with composting and crop wastes, followed by surface decomposition. Total volumes of CO_2/CH_4 from the individual/aggregated wastes in each district were pooled together to obtain the overall emission of the village, sub-county, and later district. Volumes were converted to mg. Correlation analysis was run in SPSS to determine any relationships among farm wastes/aggregated farm wastes and farm waste management methods.

2.6.2. Analysis of Carbon Dioxide from Individual Farm Wastes

From the Pearson correlations run, we could see that the correlation coefficients for Beans, Bananas, Maize, Chicken manure, and Cow dung ranged between −0.714 and −0.460, which was significant ($P < 0.01$ for a two-tailed test), based on 56 observations. Goat slurry and pig slurry had correlation coefficients of 0.467 and 0.460, respectively, which were non-significant ($P > 0.01$ for a two-tailed test), based on 56 observations. For Goat slurry and pig slurry, when a multiple regression analysis was run, $P = 0.012$, $P > 0.01$, which was non-significant ($P > 0.01$ for a two-tailed test).

2.6.3. Analysis of Carbon Dioxide from Aggregated Farm Wastes

From the correlations run, we could see that the correlation coefficients for Composting and Surface decomposition were 0.944 and 0.81, respectively, which were non-significant ($P > 0.01$ for a two-tailed test), based on 48 observations. For Composting, when a multiple regression analysis was run, $P = 0.012$, $P > 0.01$, which was non-significant ($P > 0.01$ for a two-tailed test). For Surface decomposition, when a multiple regression analysis was run, $P = 0.005$, $P < 0.01$, which was significant ($P < 0.01$ for a two-tailed test).

Surface decomposition and composting had correlation coefficient values of 0.981 and 0.944, respectively, at the 0.01 significance level (2-tailed) ($P > 0.01$). At the 0.001 significance level (2-tailed), this indicates a statistically non-significant linear relationship affecting the volumes of CO_2.

2.6.4. Analysis of Methane from Individual Farm Wastes

From the bivariate correlations run, we could see that the correlations for method and farm wastes (Beans, Bananas, Maize, Chicken manure, and Cow dung) ranged between −0.805 and −0.016, which was significant ($P < 0.01$ for a two-tailed test), based on 56 observations. When Goat slurry and pig slurry were correlated with method, their correlations were 0.884 and 0.878, respectively, which were non-significant ($P > 0.01$ for a two-tailed test), based on 56 observations. For Goat slurry and pig slurry, when a multiple regression analysis was run, their correlation coefficient was 0.884, $P = 0.468$, $P > 0.01$, which was non-significant ($P > 0.01$ for a two-tailed test).

2.6.5. Analysis of Methane from Aggregated Farm Wastes

We ran the correlation analysis to see how composting and surface decomposition were correlated to emissions in various villages, and we found that the correlation for composting was −0.790, $P = 0.20$, which was non-significant ($P > 0.05$ for a two-tailed test). Surface decomposition had a correlation of 0.978, $P = 0.000$, which was significant ($P < 0.01$ for a two-tailed test) based on 56 observations. From the Pearson correlations run, we could see that the correlation coefficient for composting and villages was 0.978, $P = 0.000$, which was significant ($P < 0.01$ for a two-tailed test), based on 56 observations.

3. Results

3.1. Carbon Dioxide

Composting beans from the arable farming system captured the highest volume of CO_2 (784.8 ppm), while maize produced more CO_2 volumes under composting (602 ppm) in the mixed farming system (**Table 1**).

Aggregated mean of Carbon dioxide (mg) by Farm waste & Waste Management Method for aggregated wastes was higher in Lyantonde up to a tune of 1219.0 ppm compared to 813.3 ppm recorded in Masaka (**Table 2**).

In Lyantonde District, CO_2 produced under surface decomposition ranged from 982.9 to 1214.9 mg. CO_2 produced under composting ranged from 803.2 to 1219.0 mg. In Masaka District, CO_2 produced under surface decomposition ranged from 538.5 to 813.3 mg. CO_2 produced under composting ranged from 490.1 to 732.9 mg (**Table 2**).

Table 1. Aggregated mean of carbon dioxide (mg/3000 cm^3) by farm waste & waste management method for individual wastes.

Waste	Masaka		Lyantonde	
	Surface deposition	Composting	Surface deposition	Composting
Beans	477.4	784.8	239.7	207.0
Goat slurry	—	—	449.1	429.2
Bananas	232.5	403.8	138.5	134.1
Maize	533.4	501.9	398.6	602.0
Chicken waste	327.9	458.4	81.3	109.6
Pig slurry	287.1	262.1	427.0	445.9
Cow dung	292.1	400.3	—	—

3.1.1. Carbon Dioxide from Aggregated Waste (See Table 2)

Table 2. Aggregated mean of carbon dioxide (mg/3000 cm^3) by farm waste & waste management method for aggregated wastes.

District	Village	Surface deposition	Composting
Lyantonde	Nakinombe	1046.1	985.2
	Kabasita	1214.9	1219.0
	Kabayanda	1150.6	9997.7
	Kitovu	982.9	803.2
Masaka	Gulama	538.5	490.1
	Buwunga	765.9	732.9
	Kakunyu	813.3	694.3
	Butale	542.6	542.2

3.1.2. Methane

Aggregated mean of methane (mg) by farm waste & waste management method for beans was the highest, with a volume of 978.7 ppm in Masaka. Pig slurry in Lyantonde produced the highest volume of Methane (556.0 ppm) (Table 3).

In Lyantonde District, CH_4 produced under surface decomposition ranged from 1196.7 to 1515.0 mg. CH_4 produced under composting ranged from 1071.2 to 1520.6 mg.

In Masaka District, CH_4 produced under surface decomposition ranged from 671.5 to 799.7 mg. CH_4 produced under composting ranged from 611.1 to 792.4 mg (Table 4).

Table 3. Aggregated mean of methane (mg/3000 cm^3) by farm waste & waste management method for individual wastes.

Waste	Masaka		Lyantonde	
	Surface deposition	Composting	Surface deposition	Composting
Beans	595.3	978.7	298.9	258.1
Goat slurry	—	—	560.1	535.2
Bananas	290.0	503.5	172.7	167.2
Maize	665.1	625.9	497.0	550.7
Chicken waste	408.9	571.7	101.4	136.7
Pig slurry	358.0	326.8	532.5	556.0
Cow dung	364.3	499.2	—	—

3.1.3. Methane from Aggregated Waste (See Table 4)

Table 4. Aggregated mean of methane (mg/3000 cm^3) by farm waste & waste management method for aggregated wastes.

District	Village	Surface deposition	Composting
Lyantonde	Nakinombe	1304.40	1228.50
	Kabasita	1515.00	1520.60
	Kabayanda	1463.40	1379.80
	Kitovu	1196.70	1071.20
Masaka	Gulama	671.53	611.18
	Buwunga	673.61	618.15
	Kakunyu	1034.43	917.89
	Butale	676.64	783.70

4. Discussion

High volumes of GHG emissions were recorded under Composting compared to what was recorded under Surface decomposition. This suggests greater efficacy of composting in mitigating CO_2 and CH_4 within and across farming systems than Surface decomposition (**Table 3** and **Table 4**). This suggests that the basic principles of composting enable more gases than surface decomposition. In the context of nutrient availability and loss due to the waste management system, we realize that the more nutrients retained in a given farm waste, regardless of being purely individual or aggregated, the lower the GHG emissions [15].

Lack of sufficient technologies and skills was among the reasons why these materials remained redundant on farms and thus were regarded or disposed of as wastes. In the same direction, more GHG emissions were generated from wastes, especially when the technologies were poor [16].

Higher volumes of CO_2 and CH_4 were recorded in Maize and Beans in Masaka compared to their counterparts in Lyantonde. This can be explained by the high volumes of the wastes produced and the traditional use of synthetic inputs [17]. On the other hand, large volumes of CO_2 and CH_4 were produced more from Goat slurry and Pig slurry from Lyantonde. This variation can be explained by the difference in the dynamics of the two farming systems to which each District subscribes. Such dynamics include methods of nutrient content, waste management, use of fertilizers, methods for nutrient recycling, procedures followed during composting, and consistency in following the correct procedures, among others. Smallholder farmers emit GHG emissions in several ways [18].

The overall emissions in Masaka (arable farming system) were lower than those of Lyantonde (mixed farming system). This is justified by the inclusion of large volumes of livestock wastes rich in N by the smallholder farmers in the mixed farming system compared to those in the arable farming represented by Masaka District [19].

In Lyantonde District, wastes from Kyabasiita Village had the highest volumes of CO_2 and CH_4 from the aggregated farm wastes compared to Kitovu Village, which had the lowest volumes (**Table 3** and **Table 4**).

In Lyantonde District, wastes from Kyabasiita Village had the highest volumes of CO_2 and CH_4 from the aggregated farm wastes compared to Kitovu Village, which had the lowest volumes (**Table 1** and **Table 2**).

For emissions from individual wastes, goat slurry had the highest volumes of CO_2 and CH_4 in Lyantonde, while bananas had the lowest volumes of CO_2 and CH_4. Maize had the highest (**Table 1** and **Table 2**).

Maize and beans are crop farm wastes with the highest volume of CO_2 and CH_4 emissions compared to the same volume of the rest of the crop wastes. For livestock, chicken waste and goat slurry generate a lot of GHG emissions compared to the same unit of cow dung and pig slurry.

Inadequate capacity or technologies to separate urine from dung, as reported by [17] [20], also applies to the rest of the wastes. This implies that for most of the time, SHFs generate and use aggregated wastes by default. Their combinations depend on the kind of crop/livestock managed [17]. In turn, the amount of emissions also relates to both the type of aggregated wastes and the quantity of such. This brings in the peanut model as a point of reference to explain the relationship between farm wastes managed and the amount of GHGs generated.

5. Conclusions

The mixed farming system produces the highest volume of CO_2 and CH_4 emissions compared to the arable farming system.

Composting has the capacity to hold GHG emissions for longer periods of time, which guarantees enough time for their conversion before they are released to the atmosphere, which is not the case with surface decomposition. In the latter, every unit of emission generated is lost to the atmosphere in the shortest period of time possible, without any delay to allow conversions.

Recommendations

Stakeholders should critically take care of farm wastes generated from the Mixed Farming System, so as to mitigate CO_2 and CH_4 emissions.

SHFs are advised to use surface decomposition as a method of WMP for crop residues that contain lower volumes of Nitrogen. Livestock wastes that contain high volumes of volatile Nitrogen should be best managed by composting. Lastly, measures should be put in place to implement practices that are environmentally safe, such as composting and recycling.

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Author Contributions

Author's role	Author's initial
Conceptualization	K.G.
Methodology	M.Y.
Validation	S.C.
Software	M.Y.
Data validation	K.G.
Data analysis	M.Y.
Resource mobilization	S.C.
Draft preparation	K.G.

Continued

Review and editing	K.G.
Visualization	K.G.
Supervision	S.C.

All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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