GREENHOUSE GAS EMISSIONS DURING WINDROW COMPOSTING AND OPEN-AIR DUMPING OF PIG MANURE WITH ADDED WOOD SHAVINGS

ABSTRACT

Aims: Toevaluate GHG emissions from two common manure management practices in Cameroon; windrow composting and Open-air dumping with and without the addition of wood shavings.
Study design: Field and laboratory experiment.
Place and Duration of Study: Waste-to-resource project site and project laboratory of the Department of Environmental Science of the University of Buea, Cameroon between February and March 2023.
Methodology: Fresh pig manure was treated in four configurations: 100% manure subjected to windrow composting, 100% manure subjected to open-air dumping, 90:10% manure: wood shavings subjected to windrow composting, and 90: 10% manure: wood shavings subjected to open-air dumping. Gas samples were collected every next morning at 10:00 AM over a period of 40 days using the static flux chamber method, and analyzed for CH_4, N_2O, and CO_2 emissions using gas chromatography.
Results: Results showed that adding wood shavings significantly reduced CH_4 and N_2O emissions across both composting and open-air dumping systems. CH_4 emissions were highest in stockpiled 100% manure (2.152 ± 1.741 mg CH_4 m² min⁻¹) and lowest in composted manure with wood shavings (0.085 ± 0.179 mg CH_4 m² min⁻¹). N_2O emissions followed a similar trend, with the highest emissions (131.3 ± 90.4 mg N_2O m² min⁻¹) recorded in stockpiled 100% manure, compared to the lowest (35.25 ± 43.50 mg N_2O m² min⁻¹) in stockpiled manure with wood shavings. CO_2 emissions were higher in treatments with wood shavings, particularly in composting (159.2 ± 70.8 mg CO_2 m² min⁻¹). Further statistical analyses confirmed significant differences in GHG emissions among the different treatments, with windrow composting consistently outperforming Open-air dumping in reducing CH_4 and N_2O emissions.
Conclusion: The study concluded that wood shavings addition and windrow composting practices significantly reduced GHG emissions from pig manure management in tropical settings.

***Keywords**: Greenhouse gas emissions, Pig manure management, Windrow composting, open air dumping, Wood shavings amendment, Aeration.*

1. INTRODUCTION

Intense anthropogenic activities has led to significant increases in atmospheric greenhouse gases (GHGs), including carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), which are major drivers of global climate change (IPCC, 2007). Over the past 150–200 years, atmospheric CO2 has increased by 30%, CH4 by 145%, and N2O by 15%, significantly enhancing the greenhouse effect (IPCC, 2007). Livestock farming substantially contributes to these emissions, particularly CH4 and N2O, released during manure management. The livestock sector contributes approximately 18% of global anthropogenic GHG emissions, with pig farming alone accounting for 37% of livestock-related CH4 emissions (Steinfeld et al., 2006). The management of pig manure is one of the primary sources of GHG emissions in pig farming, with CH4 and N2O being the most potent gases released during manure storage and treatment. The decomposition of pig manure in anaerobic conditions, such as in open-air dumping or during windrow composting, can lead to significant CH4 and N2O emissions, which have a much higher global warming potential compared to CO2 (Myhre et al., 2013). GHG emissions from pig manure management primarily arise from anaerobic microbial processes during manure storage, composting, or open-air dumping. CH4 and N2O emissions, which are 21 and 310 times more potent than CO2 in terms of global warming potential, respectively, dominate these processes (Myhre et al., 2013).

In many parts of the world, including developing countries like Cameroon, pig farming is a vital part of the agricultural sector. The industry contributes significantly to both the economy and food security, as pigs efficiently convert various feed sources into high-quality meat. The pig population in Cameroon has been steadily increasing in recent years, with an estimated population of 3.9 million pigs in 2020 which can produce about 19.46 million Kg of manure/day (FAOStat, 2020). However, this growth has resulted in higher manure production, and with it, an increase in the environmental impact of pig farming, particularly in terms of GHG emissions. Common manure management practices in Cameroon, such as open-air dumping and windrow composting, are associated with varying levels of GHG emissions, but there is a lack of detailed information on the emissions generated from these practices in tropical farming systems. Composting involves microbial decomposition of organic matter, and adding carbon-rich materials, such as wood shavings, is a common practice to improve the carbon-to-nitrogen (C: N) ratio, enhance aerobic decomposition, and reduce odours. However, the impact of wood shavings on GHG emissions during windrow composting and open-air dumping of pig manure has not been extensively studied, particularly in tropical contexts where temperature and moisture conditions can vary significantly from temperate regions.

Therefore, this study aimed to assess greenhouse gas emissions associated with two pig manure management practices in Cameroon: windrow composting and open air dumping, with a specific focus on the effect of adding wood shavings. By evaluating the emissions of CH4, N2O and CO2 during these practices, the study sought to provide a better understanding of how manure management practices can contribute to the overall GHG emissions from pig farming. Given the increasing pig population and the potential for large-scale emissions from manure management, it is crucial to develop strategies for mitigating GHG emissions in the pig farming sector. This research will contribute valuable data on local emission factors, helping to identify best practices for reducing the environmental impact of pig farming while maintaining its role in the agricultural economy of Cameroon.

2. MATERIAL AND METHODS.

2.1 DESIGN AND CONSTRUCTION OF GHG EMISSION FLUX CHAMBER

Gas concentrations were quantified using the static flux chamber method (Pihlatie et al., 2013). 7 Customised chambers were constructed from 3-litre polypropylene fowl drinkers, with the red lids modified to include a 13 cm attachment serving as an anchor. The components were securely joined using heat and silicone glue to ensure airtight seals. A permanent marker indicated a depth of 10 cm for inserting the anchor into the manure, leaving 5 cm exposed. This setup created an internal headspace volume of approximately 3.7 to 4 litres for gas sampling (fig 1). An untampered drinker was used as the head lid of the flux chamber. A 5 mm soldering iron was used to create an 8 mm hole at the bottom, where a septum was installed from the top to ensure a secure, gas-tight seal. This septum served as the sampling port for needle insertion during gas collection (Fig 2).

Fig 1: Flux chamber construction

Fig 2: The position of the septa on the flux.

2.1 Substrate Collection

The pig manure used in this study was sourced from Buea, the capital of the South West Region of Cameroon. Fresh manure was obtained from a nearby pig farm with a concreted slatted floor, approximately 2 km from the University of Buea. The farm housed fattening pigs fed with crushed pellets (Piggfor, Origo 522) produced by LantmännenLantbruk (Linköping, Sweden), which contained 129 g/kg of crude protein and 12.4 MJ/kg of metabolizable energy. The manure was considered fresh because it was collected from a pit emptied daily into an external storage or dumping area. The wood shavings used in the study were locally sourced from a sawmill in Molyko, less than 4 km from the University of Buea. These wood shavings consisted of 2 mm particle size mixture of flakes from 30–50 year old eucalyptus trees (30%), Naucleadiderrichii (opepe) (45%), and Enantiachlorantha (African whitewood) (25%).

2.3 Composting Facility

This study was conducted in a shaded yard at the Waste-to-Energy Resource project site at the University of Buea. The site comprises 18 composting chambers, each measuring 0.7 x 0.9 x 1 m (L×W×H). Each chamber features three solid cement brick walls, with an open front and top. The walls extend 1 m above the ground, and the floors are made of concrete, gently sloping towards the open front where a drainage channel collects leachates from the compost. The entire composting area is covered by a solid roof, approximately 3 m above the ground.

2.4 Experimental Set-Up

Fresh pig manure less than one day old was collected and brought to the composting site, where two 400 kg batches were prepared. One batch was homogeneously mixed with wood shavings in a 90:10 ratio (manure: wood shavings), while the other remained as 100% pig manure. Each batch was further divided into two 200 kg subsamples for composting and open-air dumping experiments (Table 1).

Table 1: Manure treatments

Open-Air dumping		Windrow composting	
100% Manure	90% : 10% Manure : wood shavings	100% Manure	90% : 10% Manure : wood shavings

Manure designated for open-air dumping (stockpiling) was placed in chambers 1 and 2, where it remained undisturbed throughout the 40-day experiment. Manure for aerated composting was placed in chambers 3 and 4. Manure in the composting chambers was turned every other day (Monday, Wednesday, Friday, etc.) throughout the 40-day composting period to ensure adequate aeration and promote microbial activity. The turning process involved transferring the contents of chamber 3 to chamber 4 and vice versa, with chamber 5 serving as a temporary holding area during mixing (Fig. 3). Standard composting protocols were adhered to for both treatments, with observations made to assess the effects of wood shavings and the aeration process.

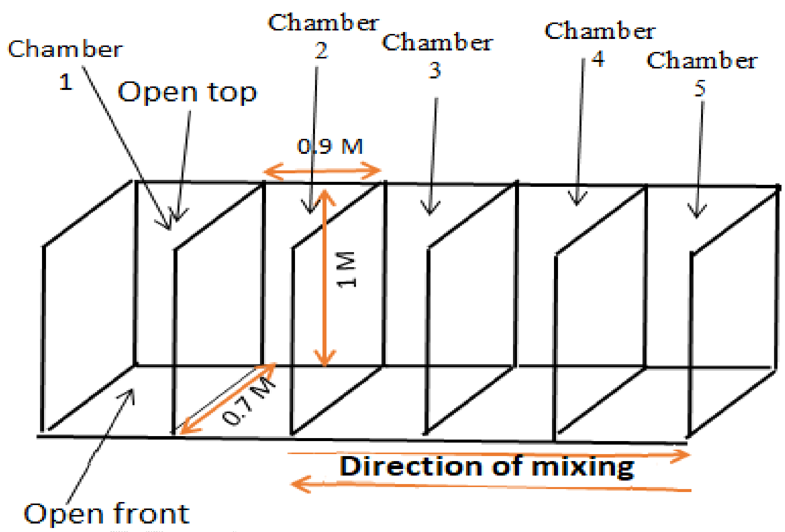
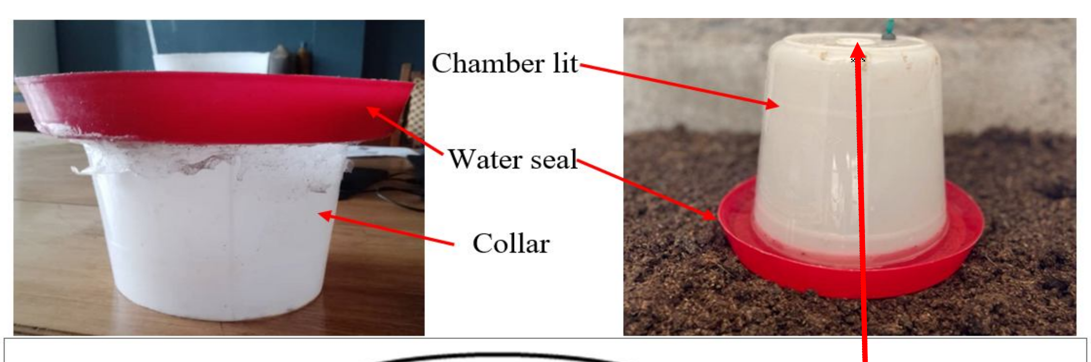


Fig. 3: Schematic diagram of composting chambers showing the direction of movement during mixing of compost manure

The static flux density chamber was employed to collect GHG data due to its suitability for comparing multiple treatments, a method commonly used in similar studies (e.g., Chadwick et al., 2000; Ginting et al., 2003; Lovanh et al., 2008; Ngwabie et al., 2018). Gas samples were taken daily at 10 AM throughout the 40-day dumping and composting periods. Flux chambers were inserted into manure piles at least 24 hours before sampling, with their positions rotated to cover different surfaces of the manure heaps. Water seals ensured gas-tight conditions, while collars were inserted 10 –11 cm into the manure for dumping and composting treatments leaving about 5 cm exposed (Fig. 4). This approach ensured consistent and reliable data collection across treatments.



During each sampling period, the chamber lid was sealed onto the collar with a water seal. Gas samples were taken from the chamber headspace at 10 minute intervals over 20 minutes (10:00, 10:10, and 10:20 AM). A syringe was used to mix the chamber air by repeatedly pulling and pushing the plunger. A 20 mL gas sample was then drawn and injected into a 10 ml glass vial with a PTFE/Silicone septum, flushing the vial with chamber air before injecting the final sample.

The overpressure created in the vial prevented contamination. Sample collection times were recorded, and the collected air samples were analyzed using gas chromatography to measure CH_4, N_2O, and CO_2 concentrations. Gas concentration data were plotted against time, and the slope of the resulting curve was calculated using linear regression to estimate gas flux. The sampling procedures were consistently followed for all chambers, with chamber and vial IDs, lid deployment, and sampling times recorded. Gas emissions were calculated by performing linear regression on the three data points from each measurement, providing a slope in ppmv min^{-1}. If the coefficient of determination (R^2) was below 0.80, the data was discarded. This threshold was set to ensure reliable gas concentration change estimates, as recommended by Ngwabie et al. (2018). The regressed slope was then converted from ppmv min^{-1} to mg m^3 min^{-1} based on the measured temperature and 760 mmHg pressure. The flux was calculated using the formula:

$$Flux = \frac{Slopexchamberheadspace}{chambercollarsurface}$$

Where the headspace volume was 0.005 m^3 and the collar surface area was 0.023 m^2.

2.5 Statistical Analysis

The data were statistically analyzed using MINITAB version 21. Analysis of Variance (ANOVA) was performed to evaluate differences in GHG emissions among the various stockpile and windrow compost piles, with significance determined at a p-value of 0.05. When significant differences were identified, a post-hoc analysis was conducted using the Tukey HSD test to show where these differences occurred.

3. RESULTS AND DISCUSSION

3.1 CH_4 emissions.

CH_4 emissions generally decreased over the sampling period for both open-air dumping and windrow composting, except for the 100% dumping treatment, which showed an increase (Fig. 5). This can be attributed to the fact that prolonged composting time produced stable, mature compost with a lower organic load and reduced GHG emissions, aligning with findings by Ngwabie et al., (2018) and Xiang-Yu et al. (2023). It has also been reported that the composting process improves the carbon-to-nitrogen (C/N) ratio over time (Ajay and Kazmi, 2009), optimising microbial growth and reducing the potential for excess carbon, which can contribute to CH4 emissions (Xia et al., 2016)

The highest CH_4 emission (2.152 ± 1.741 mg CH_4 m^2 min^{-1}) was recorded for 100% dumping, while the lowest (0.085 ± 0.179 mg CH_4 m^2 min^{-1}) occurred during 90:10 composting (Fig 5). High CH4 emissions in the C100% and D100% treatments were linked to low temperatures and high moisture content, which hindered microbial activity and created anaerobic conditions favorable for methane producing microorganisms. These conditions increased methane production, as anaerobic pockets formed in the composting and dumping systems. Similar findings were reported by Chadwick et al. (2011) and Ngwabie et al. (2018).

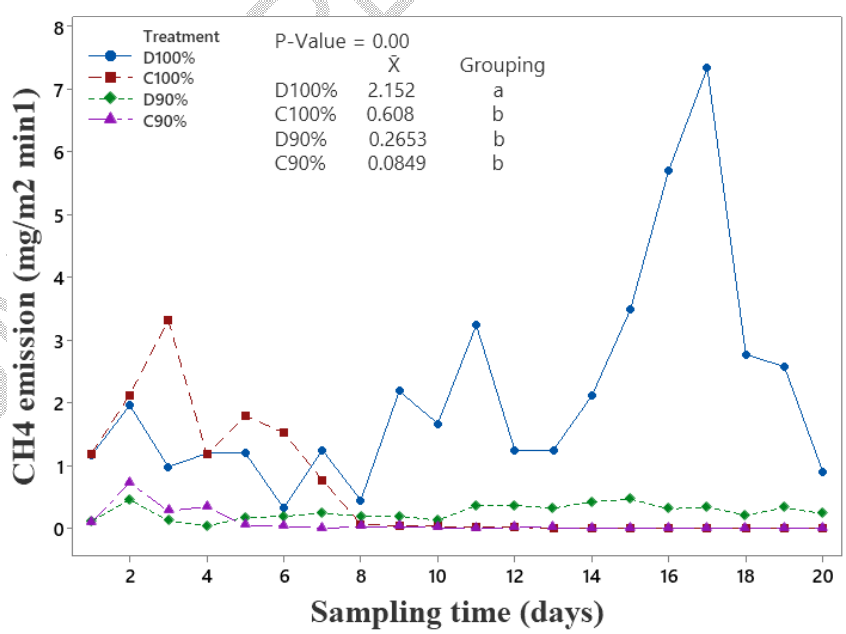


Fig. 5: CH_4 emissions during windrow composting and Open-air dumping

ANOVA results showed a significant difference in CH_4 emissions between the stockpiling and windrow compost piles (Table 5) the Tukey's post hoc analysis further revealed that the difference existed only between D100% and the rest of the other treatments. D100% had the highest CH_4 emissions due to limited aeration, caused by the absence of wood shavings and lack of turning, which created favourable conditions for methane-producing microorganisms. This result contradicts Mulbry et al. (2011), where turning after 10 days more than doubled CH_4 emissions. Many studies have shown that turning (Mulbry et al., 2011), along with the addition of additives like zeolite (Wang et al., 2017), wood vinegar (Guo et al., 2020), superphosphate (Zhang et al., 2017), and biochar (Akdeniz, 2019; Yanan et al., 2021), can enhance organic matter decomposition and reduce CH_4 emissions. The significant difference in CH_4 emissions between stockpiling and windrow composting is due to frequent turning, which aerated the pile and increased temperatures preventing anaerobic conditions (Tiku et al., 2023).

3.2 CO_2 emissions

CO_2 emissions decreased over time during stockpiling and windrow composting of pig manure. The highest CO_2 emission (159.2 ± 70.8 mg CO_2 m^2 min^{-1}) was observed in the 90:10% dumping treatment, while the lowest (88.1 ± 33.6 mg CO_2 m^2 min^{-1}) occurred in the 100:0% dumping treatment (Fig. 6). The high CO_2 emissions in the 90% treatments during windrow composting and stockpiling were due to wood shavings amendments that improved aeration, which in turn affected moisture content and temperatures. These treatments had high temperatures and low moisture content, promoting microbial activity that produced CO_2. Studies, such as Czekala et al. (2016), have also shown that amendments like biochar can accelerate organic matter degradation but increase CO_2 emissions.

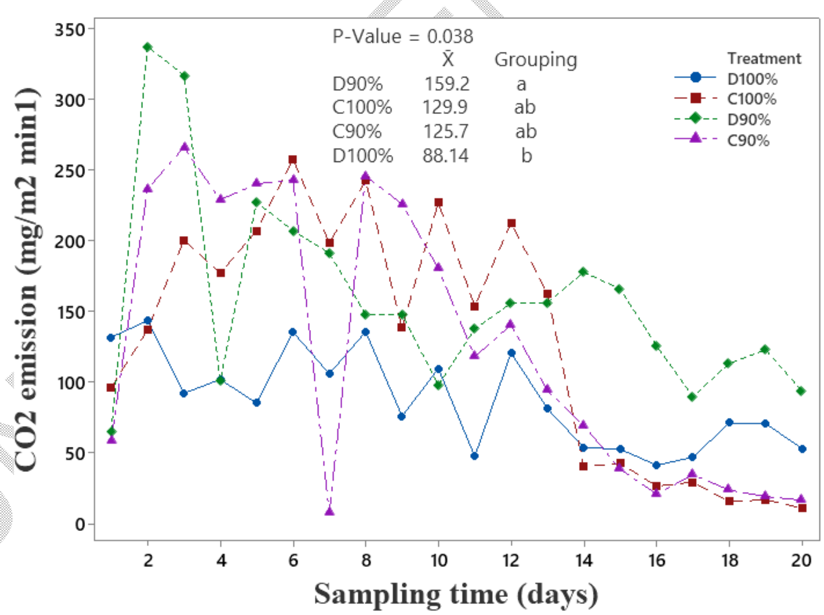


Fig. 6: CO_2 emissions during windrow composting and Open-air dumping

ANOVA results showed a significant difference in CO_2 emissions between the stockpiling and windrow compost piles. However, Tukey's post hoc analysis further revealed differences between D100% and D90%. The significant difference in CO_2 emissions between D90% and D100% treatments was due to the addition of wood shavings in the D90% treatment. Awasthi et al. (2020) found that adding 10% biochar increased CO_2 emissions by 7.4%. CO_2

emissions decreased with time in all treatments, correlating with microbial activity, as reported by Petric et al. (2009), who found that CO_2 mass was directly proportional to microbial activity during composting.

3.3 N_2Oemission.

The highest mean N_2Oemission during open-air dumping and windrow composting (131.3 ± 90.4 mg N_2O m^2 min^1) was recorded during 100% dumping while the lowest mean N_2O emission (35.25 ± 43.50 mg N_2Om^2 min^1) was observed during 90:10% dumping (Fig 7). The high N_2O emissions in the 100% treatments stockpiling and windrow composting can be attributed to the high nitrogen content in pig manure, which is a significant nitrogen source (Renjie et al., 2022). The increased nitrogen availability in the 100% treatments stimulated microbial activity and enhanced denitrification, leading to higher N2O emissions.

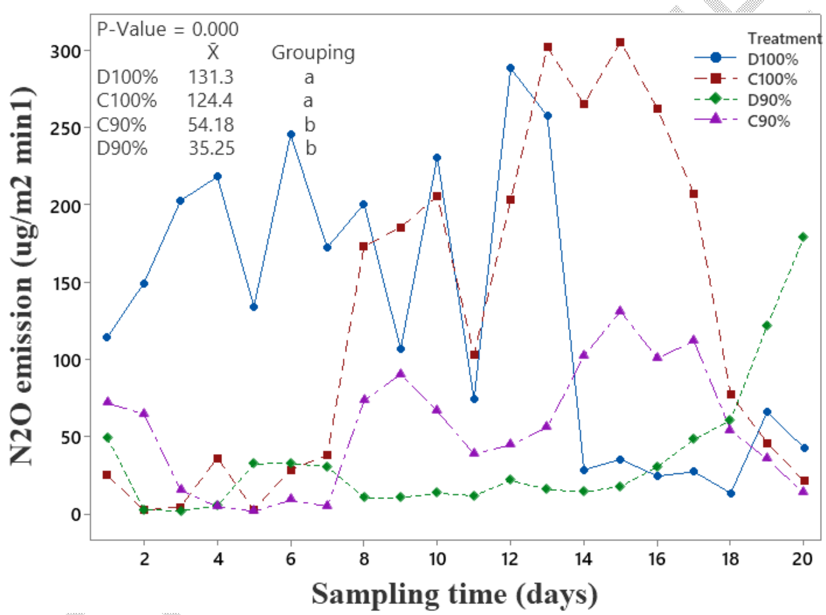


Fig. 7: N_2O emission during windrow composting and Open-air dumping

ANOVA results indicated a significant difference in N_2O emissions between open-air dumping and windrow composting treatments. Tukey's post hoc analysis revealed no difference between D100% and C100%, or between D90% and C90%, but both D100% and C100% differed from D90% and C90%, due to the addition of wood shavings in the 90% treatments, which improved the C/N ratio. An optimized C/N ratio reduces nitrogen loss as N_2O emissions (Corbala-Robles et al., 2018). High moisture content and limited aeration in the 100% treatments created favorable conditions for denitrification, leading to higher N_2O emissions, as reported by Hellebrand (1998), Fukumoto et al. (2003), and Szanto et al. (2007). However, Ahn et al. (2011) found that increased aeration raised N_2O emissions.

Table 2. : Comparison of GHG emissions from the different pig manure treatments during open-air dumping and windrow composting

Treatments	Open-air dumping and windrow composting

	CH_4		CO_2		N_2O	
D100%	2.152 [a]		88.14 [b]		131.30 [a]	
D90%	0.270 [b]		159.20 [a]		35.25 [b]	
C100%	0.608 [b]	P = 0.00	129.90 [ab]	P=0.04	124.40 [a]	P=0.00
C90%	0.085 [b]		125.70 [ab]		3.35 [a]	

A statistically significant difference was observed in CH_4, CO_2, and N_2O emissions between open-air dumping and windrow composting treatments (Table 2), this can be attributed to variations in aeration, moisture levels, temperature, and microbial activity. In open-air dumping, particularly in treatments such as D100%, anaerobic conditions prevail, promoting methanogenesis (resulting in higher CH_4 emissions) and denitrification (leading to higher N_2O emissions). In contrast, windrow composting, which involves regular aeration and elevated temperatures, encourages aerobic decomposition, leading to higher CO_2 emissions but lower CH_4 and N_2O emissions. These findings align with previous research by Chadwick et al. (2011), Ngwabie et al. (2018), and Ahn et al. (2011), which highlight the critical role of aeration, temperature, and nitrogen management in regulating GHG emissions during composting and other organic waste treatment processes.

3.4 Effect of turning and wood shavings amendment on GHG emission during open-air dumping and windrow composting of pig manure.

Turning of pig manure without wood shaving amendments reduced CH_4 and N_2O emissions by 71.75% and 5.28% respectively but increased CO_2 emissions by 47.43% (Table 4.).

Table 3: Emission reduction potentials of turning and wood shaving amendments during open-air dumping and windrow composting.

Treatments	Effect of turning	
	100% (%)	**90% (%)**
CH_4	71.75	67.99
CO_2	- 47.43	21.04
N_2O	5.28	- 53.70

Turning with 10% wood shaving amendment reduced CH_4 and CO_2 by 67.99% and 21.04% respectively but increased N_2O by 53.70% (Table 3).

The reduction in CH_4 and N_2O emissions from turning manure can be linked to the enhanced aeration that prevents anaerobic conditions, limiting the processes that produce these gases. Studies by Chadwick et al. (2011) and Ahn et al. (2011) showed that turning manure promotes aerobic conditions, boosting microbial activity that breaks down organic matter into CO_2 instead of CH_4 and N_2O. Other research, including work by Mulbry et al. (2011) and Fukumoto et al. (2003), supports this by demonstrating that turning reduces anaerobic pockets, thereby lowering GHG emissions.

10% wood shavings amendments reduced CH_4 and N_2O emissions by 87.67% and 73.16% respectively but increased CO_2 emissions by 80.66% during open-air dumping of pig manure (Table 4.), while it reduced CH_4, CO_2, and N_2O emissions by 86.03%, 3.23% and 56.44% respectively. The reduction in CH_4 and N_2O can be attributed to improved aeration, which minimizes anaerobic conditions that promote methane and nitrous oxide production. This enhanced aeration supports aerobic microbial activity, which converts organic matter into CO_2 instead of methane or nitrous oxide (Chadwick et al., 2011; Ahn et al., 2011). Additionally, the wood shavings likely improved the C/N ratio of the manure, reducing excess nitrogen and further limiting N_2O emissions (Corbala-Robles et al., 2018). The increase in CO_2 emissions is a result of the shift toward aerobic decomposition, which accelerates organic matter breakdown, releasing CO_2 (Mulbry et al., 2011; Fukumoto et al., 2003). These findings align with previous studies highlighting the benefits of amendments like wood shavings in enhancing aeration and microbial activity while reducing potent greenhouse gas emissions.

3.5 GHG emission factor

D100% had the highest emission potentials with the highest Carbon dioxide emission equivalent while C90% had the lowest during open-air dumping and windrow composting of pig manure (Table 4.).

Table 4: GHG emission factor during Open-air dumping and windrow composting of pig manure

Treatments	CO_2eqCH_4 (mg)	CO_2 (mg)	CO_2eqCH_4 (mg)
D100%	1076.02	2626.35	525.31
C100%	303.99	2487.58	774.40
D90%	132.65	704.93	949.00
C90%	42.46	1083.51	749.38

The high GHG emission factor observed in D100% can be attributed to the anaerobic conditions that promote CH_4 and N_2O production (Table 4). This is consistent with studies by Chadwick et al., (2011) and Ngwabie et al., (2018), which emphasized the role of anaerobic environments in enhancing CH_4 and N_2O emissions. In contrast, C90% had the lowest emission factor due to the improved aeration from wood shavings, which encouraged aerobic conditions and reduced CH_4 and N_2O emissions. These findings are supported by Ahn et al., (2011) and Fukumoto et al., (2003), who found that aeration through amendments like wood shavings promotes aerobic decomposition, thus lowering GHG emissions. Additionally, the wood shavings likely improved the C/N ratio, reducing excess nitrogen and further limiting N_2O production, as noted by Corbala-Robles et al., (2018). These results underscore the importance of aeration and nutrient management in controlling GHG emissions during manure management.

4. CONCLUSION

Windrow composting, especially with the addition of wood shavings, appears to be a more environmentally sustainable method for managing pig manure in tropical regions like Cameroon. This practice reduced GHG with increasing monitoring days. 100% treatments emitted more CH_4, and N_2O than 90% treatments but the 90% treatments emitted more CO_2 than 100% treatments. Turning without wood shaving reduced CH_4 and N_2O emissions by 71.75 % and 5.28 % respectively. Turning with 10% wood shaving reduced CH_4 and CO_2 emissions by 67.99% and 21.04% respectively but increased N_2O by 53.70%. Wood shavings amendments reduced CH_4 emissions by 87.67% and 86.03% during dumping and composting respectively. Wood shavings amendments reduced N_2O emissions by 73.16% and 56.44% during dumping and composting respectively. These findings suggest that adopting windrow composting, particularly with amendments like wood shavings, could serve as an effective strategy for reducing the environmental impact of pig farming while maintaining the sector's economic viability.

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