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Carbon to Nitrogen ratio variation effects on biogas systems performance in Uganda: A facile substrate based comparative study

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ABSTRACT

This study aimed at finding out the effects changes in Carbon to Nitrogen (C/N) ratios have on biogas systems performance particularly in terms of the amount of biogas output, the methane percentage composition and the time the feed stocks remain active through the study. This research work presents the experimental results of the anaerobic digestion of various types of biomasses basing on C/N ratios. The animal manure substrates used in this study were; poultry litter (PL), cow dung (CD), mixture of poultry litter and cow dung (M_1), poultry litter mixed with piggery manure (M_2), cow dung mixed with piggery manure (M_3). The C/N ratios of the substrates were 15.00, 22.00, 1.04, 16.00 and 5.50 respectively. These substrates were maintained at mesophillic temperatures (35^0C) separately. Particular attention was focused on the productivity of the substrates, measuring daily biogas production by the method of downward displacement of water and methane composition using an Orsat gas for 29 days. **M_2** gave the highest values in terms of both the peak values of biogas and methane (0.76 L and 0.446 L respectively) and the highest total biogas output as well at 8.96L. CD took the longest biogas production time and showed even potential to go beyond the set experimental time of 29 days though it took comparatively longer to start. CD had the second highest in total biogas output at 6.27L of biogas followed by PL at 4.25L, M_3 at 2.70L and M1 at 1.95L. The cumulative methane composition correlated well with the total biogas output with only M_3 giving a higher methane output of 0.68L compared to PL at 0.25L. In this research, it was found that the C/N ratio was proportional to the biogas system active time as well as the total biogas output.

Keywords: *Renewable energy, Biogas, C/N ratio, substrate*

1.0 INTRODUCTION

1.1 Back ground

The control of atmospheric emissions of greenhouse and other gases and substances in Uganda will increasingly have to be based on efficiency in energy production, transmission, distribution and consumption (World Bank, 2005). Modern bioenergy technologies such as biomass gasification, cogeneration, biogas generation, biomass densification, and energy-efficient cooking stoves have been introduced in Uganda but have certainly not been widely disseminated (Okello, Pindozzi, Faugno, & Boccia, 2013).

Uganda has the potential to produce about 1,258.37 million m3 of biogas annually, which is equivalent to 25.17 PJ of energy from livestock wastes (Owusu & Banadda, 2017).

Appropriate raw material for biogas production must involve organic material that is suitable for anaerobic digestion. The energy production potential of feedstock depends on the type, level of processing or pre-treatment and concentration of biodegradable material. The C/N ratio, which is fully written as carbon to nitrogen ratio is regarded as the ratio of the elemental carbon present in the material to the elemental nitrogen present in the material. Different materials have their C/N ratio, but mixture of different materials can alter the overall C/N ratio of the total feedstock (Okonkwo, Onokpite, & Onokwai, 2018). A C/N ratio ranging from 20 to 30 is considered optimum for anaerobic digestion(Fantozzi & Buratti, 2009). However efforts to have substrates match this range are still lacking (Dandikas, Heuwinkel, Lichti, Drewes, & Koch, 2014). In Uganda the commonest biogas feedstock are; cow dung, Piggery manure and Poultry litter(Owusu & Banadda, 2017). It still remains abstract to many biogas operators; both domestic and commercial on which substrate or co-substrate to adopt basing on the retention time, biogas output and methane percentage composition yet this is key(Mutai et al., 2016).

1.2 Problem Statement

The global depletion of energy sources and the adverse effects of fossil fuels on the environment pose a challenge to devise alternative energy sources. Among the efforts to combat the problem is the use of renewable energy sources of which biogas systems are part. In Uganda, the spread of this technology is still limited. Most of the biogas systems are no longer functional and those in operation are not performing to the expected outputs (Mutai et al., 2016). Besides the economic and social factors is the poor control of anaerobic digestion parameters which are the pinnacle for any biogas system performance (Labatut, Angenent, & Scott, 2014; Ziganshin, Liebetrau, Pröter, & Kleinsteuber, 2013). Since most of the biogas systems are operated at home level by mostly non-technical users, they are not aware of the appropriate C/N ratios for effective system performance. This research aimed at evaluating the performance of biogas systems with varying C/N ratios based on substrates.

1.3 Purpose

The core purpose of this study was to identify the appropriate C/N ratio ranges for the chemical reactions involved in each stage of biogas production and hence ascertain the effect C/N ratio has on percentage composition of the biogas output.

1.4 Research Question

What are the effects of C/N ratio variations on the performance of biogas systems in Uganda?

1.5 Scope

This study evaluated the performance of different substrates with varying C/N ratios in terms of biogas out puts and the methane percentage composition in the biogas.

1.6 Organization of the article

The background to the research problem and the significance of the study are presented in section 1. Section 2 entails the methods and materials used. These include the equipment adopted as digesters, the collection and preparation of the feedstocks and the analysis of the substrates. The results from the study are presented in section 3 and discussions of the same are presented in section 4.

2.0 METHODS AND MATERIALS

2.1 Feed Preparation

In this study the following animal manure substrates were analyzed: Poultry litter (PL) mixed with water, Cow dung (CD) mixed with water, mixture of poultry litter and piggery manure from a local digestion Plant (M1), cow dung mixed with piggery manure (M2), Poultry litter mixed with piggery manure (M3). These substrates were chosen because they are the commonest feedstock for biogas digesters in Uganda and their C/N ratios are known. The proportions in which the substrates could be mixed to attain particular C/N ratios were standard and this helped to prepare the samples and widen the range for the analysis used in this study (Table 2).

Table 1: proximate and ultimate analysis results for the substrates(Fantozzi & Buratti, 2009)**.**

Element composition	Substrate				
	Poultry litter	Cow dung	M_1	M_2	M_3
C/N ratio	15.00	22.00	1.04	16.00	5.50

The poultry litter and piggery manure were collected from a farm in Kiwawu Village - Malangala Sub County in Mityana district-Central Uganda. Fresh cow dung was collected using a wheelbarrow from an abattoir near Malangala Sub-County headquarters in Mityana district, Uganda. It was sorted to remove other indigestible materials like stones and metals. It was then kept covered in a heap with polythene bags at ambient temperature (25±20C) for two weeks before the experiment.

Table 2: Masses of substrates in kg used to prepare feed stock mixtures

Masses of substrates in g used to prepare M_1, M_2 and M_3.	Substrate mixture		
	M_1	M_2	M_3
Poultry litter	1.0	1.4	-
Cow dung	3.0	-	2.0
Piggery manure	-	1.8	1.0
Water [b]	1.0	1.8	2.0

[b]= measured in litres during the experiment

2.2 Equipment

The reactors used in this experiment were five 250cm3 Perspex cylindrical flasks tightly sealed with rubber corks and labeled PL, CD, M1, M2 and M3 corresponding to the feed stock put in the reactor. The gas given off was tapped off through rubber tubes to the disposable calibrated syringes partially under water and held by retort stands. The outlets of the syringes were blocked with clipped rubber tubes. After 6-8 days the air inside the containers had to be released so that only pure gas was inside. It had to be ensured that the syringes were filled with water before releasing. The tube clips were loosened to let the air leak out until it began to smell. Sampling and measurements started after 8-13 days and were taken daily till the reactors went passive and those that were still active after the 29h day had to be terminated. Shaking the flasks twice a day in the morning and evening hours always did the agitation. A constant temperature of 35° C (mesophillic) was maintained through a thermostatically controlled water bath for each reactor for a total of 29 days.

2.3 Chemical Analysis

The biogas composition was analysed using an Orsat gas analyser (model; A-00621-AO). The gas analyser had been calibrated 2 months before the study. Sampling was done by sucking through the cork using a 5 ml medical syringe and pH was measured using a pH metre (AR20 pH/conductivity meter).

3.0 RESULTS

3.1 Biogas production rate at the start

All the reactors were inactive for the first days with the earliest going active on day 7 and the latest on day 14 as shown in Figure 1 since no bacteria had accumulated due to no sludge added. Even still all substrates took 2-3 days less time compared to the individual substrate wait times available in literature before start of biogas production. This is because the substrates had been kept in oxygen free cool environment for two weeks before the experiment. It was noted that some reactors continued for 1 to 2 days producing gas with no methane before they completely terminated. This could signify the exhaustion of carbon that takes part in methane formation. This was evident in the reactors with low C/N ratios (M_3, M_1 and PL) (Figure 1).

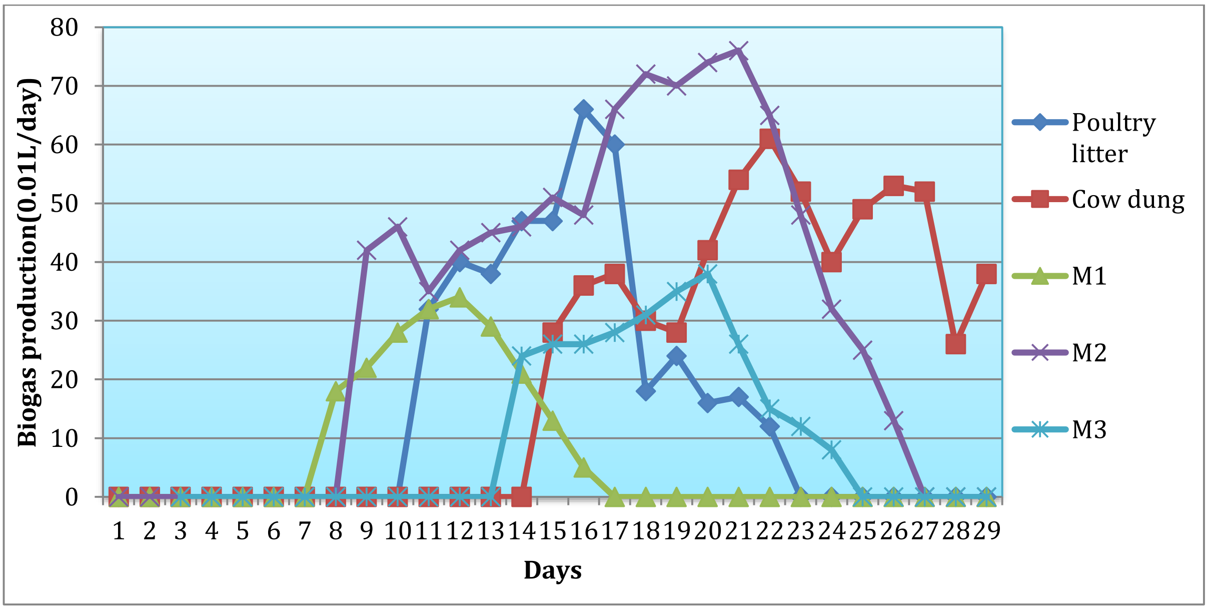

Figure 1: Daily biogas production from different substrates

3.2 Progressive biogas production rates and methane % compositions

M_1 was the first to produce gas on day 8 but in very low amounts compared to **CD, PL and M_2**. It showed a steady increase in biogas production to day 12 then it started to reduce. This showed the least number of days of active gas production (9 days). Its biogas production level peaked (0.32L/day) on day 11 of digestion and then gradually decreased to 0.05L/day on day 16 after which it completely ceased. **M_2** gave the highest values in terms of both the peak values of biogas and methane (0.76 L and 0.446 L respectively). The total biogas production was 8.96 L of gas the highest of the five reactors. From those values it could be considered successful even though it terminated earlier than that of pure cow dung. Poultry Litter (**PL**) test started producing biogas on day 11 in good amounts, showed steady increase up to its peak on day 16 (0.66 L of gas/day) after which it started to decrease and ceased on day 22. Its methane production was so insignificant, its composition ranged from 4.6 to 9.7% that is so low for gas combustion (Figure 3).

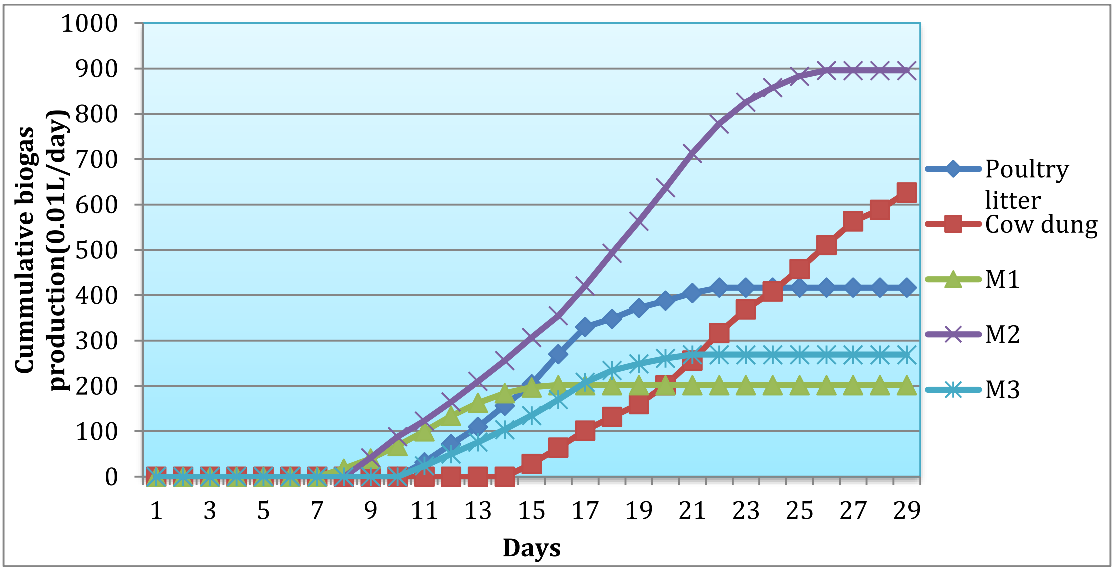

Figure 2: Cumulative biogas production per substrate

The reactor with Cow dung (**CD**) took comparatively longer time for biogas production to start (day 14), it showed the highest active time that even its production was terminated due to time factor. It could go over 29 days unlike the rest that naturally terminated. The biogas output from cow dung reactor was 0.28 – 0.53 L/day. It gave the second highest total biogas production (6.27 L of gas) for the 29 days of monitoring (Figure 2). Its biogas peak value (0.61 L/day) was on day 22 and methane peak (0.314 L/day) on day 21 (Figure 3). **M_3** was insignificant in its biogas output though better than the **PL** and **M_1**. It produced the peak biogas amount 2 days to termination and in the last two days the biogas had no methane at all. For the 29 days M_2 had the highest methane produced as shown in Figure. This correlated well with the total biogas output.

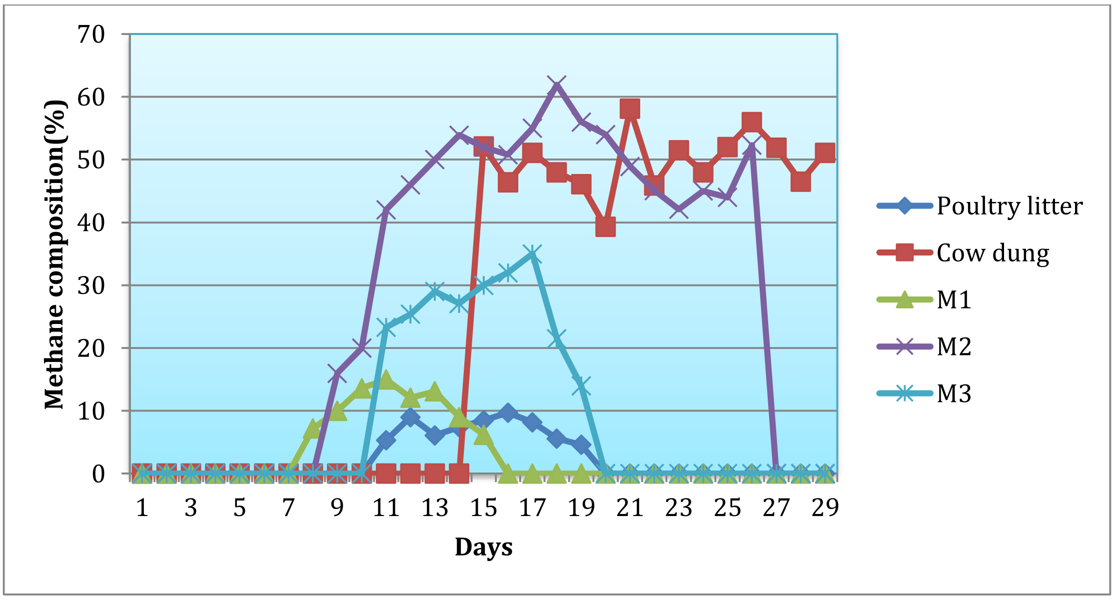

Figure 3: Methane percentage composition per substrate

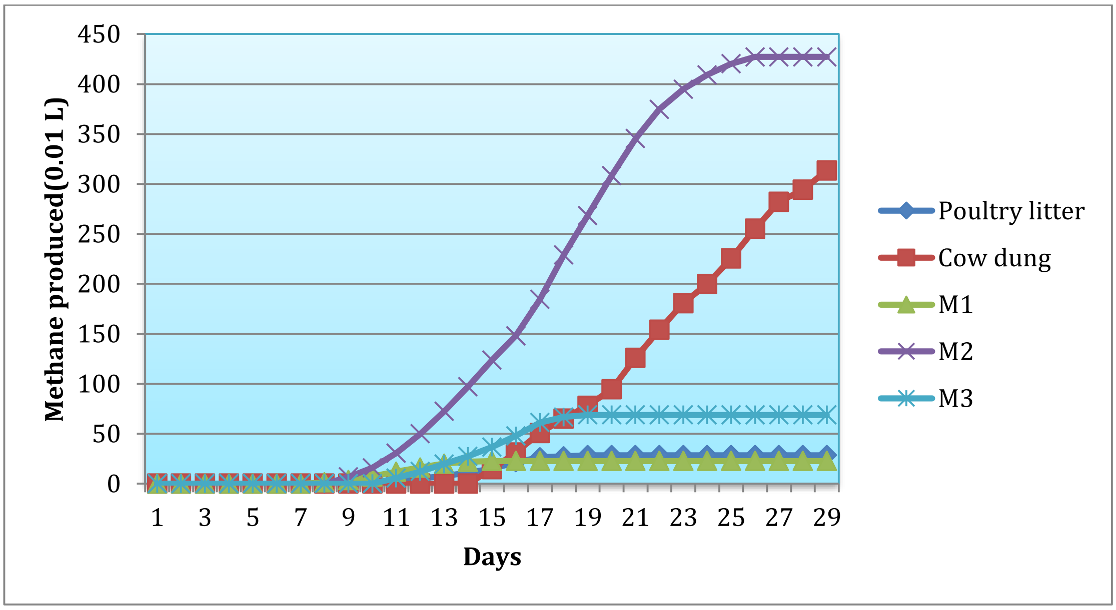

Figure 4: Cumulative methane composition per substrate

4.0 DISCUSSION OF RESULTS

4.1 Biogas production

The passivity of the reactors during the first days could be attributed to the dissolved oxygen in the substrates that impeded aerobic digestion(Okonkwo et al., 2018). Although an increasing biogas production was observed from all test units during the first days after production began, there was not much methane produced during those days. This is due to the oxygen that dissolved in the water used in preparing these feeds and also remained in the pore spaces of the bio solid, the most of biogas production during the first days could have probably come not through anaerobic digestion but aerobic or anoxic degradation(Okonkwo *et al.*, 2018). CD had the longest digester active time. It was terminated at day 29 while the rest naturally ceased to produce any biogas before day 29. This is attributed to the highest C/N ratio implying anaerobes had more carbon to act on. M_2 produced more biogas than CD due to the combination of both poultry litter and piggery manure that are excreta of non-ruminants. This implies that starch for these substrates was still in abundance for bacteria to act on and also effect methanogen growth(Alfa, Dahunsi, Iorhemen, Okafor, & Ajayi, 2014). The dissipation of the readily degradable materials may have caused temporal biogas production decrease approximately halfway their retention times (Demirer & Chen, 2008; Lu *et al.*, 2007).

4.2 Biogas methane composition

All the tests gave relatively low methane composition peak values compared to those obtained by other scholars(Zhou, Zhang, & Dong, 2012). This could have been due to the maintenance of the reactors in the same temperature range that some bacterial consortium that could convert intermediate products of the bio- chemical reactions could not easily adapt to it (Labatut et al., 2014; Lohani, Wang, Bergland, Khanal, & Bakke, 2018). Methane production increased progressively generally for all the substrates. This is because the aerobic bacteria were being substituted by acid forming bacteria and the carbon to be acted on was still abundant. This progressed up to peak values after which it gradually dropped. This is because the carbon content reduces over time and the C/N ratio reduces up to when the bacteria feeding more on Nitrogen suppress those that act on carbon. It is pertinent to co-digest the animal wastes with crops for better methane yield (Nges, Escobar, Fu, & Björnsson, 2012; Zhou et al., 2012). In the same way this can help sustain better biogas production even with biogas latrines solving an issue raised by Mutai *et al.*, (2016).

4.3 Policy implications of the study

It is pertinent to change the design of digesters to have methanization chambers where substrates can be transferred after the first 11-12 days of digestion. This shall enable tapping of high quality biogas.

4.4 Limitations of the study

The C/N ratios of substrates were based on theoretical values from past studies. They were not determined in this study. The compositions of animal manure are dependent on a number of factors among which are the feeds and the weather conditions they are subjected to.

5.0 CONCLUSONS AND RECOMMENDATIONS

5.1 Conclusions

The higher the C/N ratio the higher the biogas produced. However the digesters may produce high biogas output but with relatively low methane content.

Animal manure can be improved as a substrate regarding production of higher biogas amounts with better methane composition by mixing it with crop residues.

Substrates of high C/N ratio may produce unexpectedly lower biogas and lower methane percentage compositions if maintained at the same temperature regimes.

5.2 Recommendations

It is appropriate to separate digesters such that after the first days of digestion the feedstock can be delivered to a methanization chamber where good methane compositions can be tapped. This helps also to reduce time lags in case used up slurry has to be removed in case of batch fed digesters.

Low C/N ratio substrates are more suitable for continuously fed digesters than batch fed. This is because continuous feeding can help maintain a level of carbon content despite the depletion in a short time.

If low C/N ratio substrates are to be used in biogas production they should be inoculated with sludge to reactivate digestion by introducing new acid forming bacteria.

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