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Effect of Co-Digestion on Anaerobic Digestion of Cattle Slurry with Maize Cob at Mesophilic Temperature

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Abstract
Attempt was made to determine the effect of co-digestion on anaerobic digestion of cattle slurry (CS) with maize cob (MC). The experiment was carried out in a laboratory scale batch experiment. Cow Slurry and Maize Cobs were co-digested at ratios 3:1, 1:1 and 1:3 using the percentage volatile solid of each substrate. Co-digestion of CS with MC at 3:1, 1:1 and 3:1 under mesophilic temperature (37^{o}C) gave biogas yields of 453.38, 417.30 and 428.92 l_N/kgoDM respectively while the methane yields were 334.18, 323.63 and 323.27 l_NCH_4/kgoDM respectively. Methane concentrations of 73.71, 77.55 and 75.37% were obtained at CS: MC combinations of 3:1, 1:1 and 1:3 respectively. The study revealed that co-digesting CS with MC at ratio 3:1 is optimum for biogas production.
Keywords: co-digestion, cattle slurry, maize cob, batch experiment, mesophilic temperature

1. Introduction

Biogas, the gas produced when organic matter of animal or plant ferments in an oxygen-free environment occurs naturally in swamps and spontaneously in landfills containing organic waste. It can also be induced artificially in digestion tanks to treat sludge, industrial organic waste, and farm waste (Igoni, *et al*., 2008). Biogas primarily consists of methane (CH_4) and carbon dioxide (CO_2), with varying amounts of water, hydrogen sulphide (H_2S), oxygen and other compounds (Madu and Sodeinde, 2001, Keefe and Chynowet, 2000). Millions of cubic metres of methane in the form of swamp gas or biogas are produced every year by the decomposition of organic matter, in form of both animals and vegetables. It is almost identical to the natural gas pumped out of the ground by the oil companies and used by many people for heating houses and cooking meals. In the past, however, biogas has been treated as a dangerous by-product that must be removed as quickly as possible, instead of being harnessed for any useful purposes. It is only in very recent times that a few people have started to view biogas, in an entirely different light, as a new source of energy for the future.

High methane yield can be achieved through co-digestion of manure with energy crops and or their residues. Co-digestion with animal manure or sewage sludge as base feedstock is an effective way to improve buffer capacity and achieve stable performance (Sosnowski *et al*., 2003; Murto *et al*., 2004; Mshandete *et al*., 2004; Umetsu *et al*., 2006). Also, the addition of readily biodegradable organic matter into animal manure digester could significantly increase biogas production due to the changes of feedstock characteristics. To this end, this work investigated the effect of co-digestion on biogas production using cattle slurry and maize cob.

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2. Materials and Methods

2.1 Sources of organic materials

Maize plants were harvested from the Institute for Animal Breeding and Animal Husbandry (ABAH), Ruhlsdorf / Grosskreutz, Germany and the cobs were separated for experimentation. Cattle slurry was also obtained from the same institute (ABAH).

2.2 Methodology

Samples of cattle slurry and maize cobs were kept in the laboratory at a +3°C after size reduction prior to feeding into the digester. The amount of substrate and seeding sludge weighed into the fermentation bottles were determined in accordance to German Standard Procedure VDI 4630 (2004) using the equation (1):

$$\frac{oTS_{substrate}}{oTS_{seeding\ sludge}} \leq 0.5 \qquad (1)$$

Where:

oTS $_{substrate}$ = organic total solid of the substrate and;

oTS $_{seeding\ sludge}$ = organic total solid of the seeding sludge (the inoculum)

Equation (1) can be modified to read

$$p_i = \frac{m_i . c_i}{m_s c_s} \qquad (2)$$

Where

p_i = mass ratio = 2 ; m_i = amount of inoculum, g

c_i = Concentration of inoculum, oDM in % Fresh mass

m_s = amount of substrate, g

c_s = Concentration of substrate, oDM in % fresh mass

Two bottles were used for each of the combinations and the average yields found at the end of the experiment. At the beginning of the experiment, anaerobically digested material from a preceding batch experiment was used as inoculums for this study. the substrates fed into the digestion bottles were calculated using equation (2) and found to be 57.3g CS / 0MC (100% Cattle slurry with no maize cob), followed by 25.79g CS / 1.161g MC (75%CS and 25%MC), 15.20gCS/ 2.84g MC (50%CS and 50%MC), 8.61gCS/4.82gMC (25%CS and 75%MC) and 0gCS/10.70gMC (100%MC). The calculated amount of the substrates (using equation 1) was added to 800g inoculum to ensure compliance of the $oDM_{feedstock}$ to $ODM_{inoculum}$ ratio being less or equal 0.5 as it is recommended in VDI 4630 (equations 1 and 2). Two digestion vessels were also filled with 800g of inoculums only as control. To maintain a constant temperature, the digestion bottles were then transferred into the thermostatic cabinet heater (Plate 1) set at 37°C (mesophilic temperature) according to German Standard Procedure VDI 4630 (2004). The experiments were carried out and replicated as described by Linke and Schelle (Linke and Schelle, 2000). Biogas production and gas quality from maize cob (MC) and cattle slurry (CS) were analyzed using the gas analyzer, GA 2000. Characteristic chemical parameters of the inoculum used are summarized in Table 1. The biogas produced was collected in scaled wet gas meters for 34 days. This duration of the test fulfilled the criterion for terminating batch anaerobic digestion experiments given in VDI 4630 (daily biogas rate is equivalent to only 1% of the total volume of biogas produced up to that time). The volume of the gas produced was measured daily. Besides, other gas components, methane (CH_4) and carbon dioxide (CO_2) contents were determined at least eight times during the batch fermentation test using a gas analyser GA 2000. The tests were conducted in two replicates. Plate 1 shows the set up of the batch experiment conducted at mesophilic temperature (37°C).

Quantitative evaluation of the results gained in batch anaerobic digestion tests included the following steps: standardizing the volume of biogas to normal litres (1_N); (dry gas, t_0=273 K,p_0=1013hPa) and correcting the methane and carbon dioxide contents to 100% (headspace correction, VDI 4630). Readings were analyzed using Microsoft Excel spread sheet together with the “Table curve” computer software. Accumulated biogas yields over the retention time were fitted by regression analysis using Hill-Kinetic equation in order to determine the maximum biogas and methane potentials of the selected substrates.

Readings of the gas production (ml), air pressure (mbar), gas temperature (°C) and time of the day were taken on daily basis throughout the period of the experiment. The gas was analysed with the use of gas analyser GA 2000 at least twice per week for the four weeks of the experiments. The gas factor was calculated as well as the fresh mass biogas and methane yield with the volatile solid biogas and methane yields also determined on daily basis. The amount of gas formed was converted to standard conditions (273.15 K and 1013.25 mbar) and dry gas. The factor was calculated according to equation (3).

$$F = \frac{(p - P_{H_2O}).T_o}{(t + 273.15).p_o} \tag{3}$$

Where
T_o= 273.15 ^oC (Normal temperature)
t= Gas temperature in ^oC
P_o= 1013.25 mbar (standard pressure)
P= Air Pressure

The vapour pressure of water P_{H_2O} is dependent on the gas temperature and amounts to 23.4 mbar for 20^oC. The respective vapour pressure of water as a function of temperature for describing the range between 15 and 30^oC is given as in equation (4)

$$P_{H_2O} = y_o + a.e^{b.t} \tag{4}$$

Where:
y_o = -4.39605; a = 9.762 and b= 0.0521
The normalized amount of biogas volumes is given as

$$Biogas[N\,ml] = Biogas[ml] \times F \tag{5}$$

Normalized by the amount of biogas, the amount of gas taken off of the control batch is given as

$$Biogas[N\,ml] = (Biogas[Nml] - Control[Nml]) \tag{6}$$

The mass of biogas yield in standard liters / kg FM fresh mass (FM) is based on the weight
The following applies:
1 standard ml / g FM=1 standard liters / kg FM = 1 m^3 / t FM

$$Mass\ of\ biogas\ yield = \sum \frac{Biogas[N\,ml]}{Mass[g]} \tag{7}$$

The oDM biogas yield is based on the percentage of volatile solids (VS) in substrate

$$oDM\ biogas\ yield = \sum \frac{Biogas[N\,ml).100]}{Mass[g].VS[\%FM]} \tag{8}$$

$$CH_{4corr.} = \frac{CH_4[vol\%].100}{(Mass[g] + CO_2[vol\%])} \tag{9}$$

$$Fresh\,Mass\,Methane\,yield = \frac{Fresh\,mass\,biogas\,yield \times CH_{4corr.}}{100} \tag{10}$$

$$oDM\ Methane\,yield = \frac{oDM\ biogas\ yield \times CH_{4corr.}}{100} \tag{11}$$

2.2 Substrates and Analytical Procedures

Sample of maize cob (MC) was investigated for Fresh matter (FM), organic Dry Matter (105^oC), Organic Dry Matter in % fresh mass, Volatile fatty acids (VFA), pH, NH_4-N, Conductivity (LF), Organic dry matter in % of fresh mass (oTS). The inoculum for the batch anaerobic digestion tests was also analyzed for the following parameters DM, ODM, pH, organic acids and the electrical conduction. All analyses were performed according to German standard methods (Linke and Schelle, 2000).

3. Results and Discussion

Table 1 shows the results of the chemical analysis of the selected substrate before digestion. The cumulative biogas and methane productions obtained from batch digesters are shown in Figures 1-2.

3.1 Substrates

The dry matter (DM), organic dry matter (oDM), NH_4-N, Crude Fibre, N, P, K, pH, and the conductivity of the selected substrates determined are as shown in Table 1 (Kirchgeßner, 1997; Mähnert *et al*., 2002).

3.2 Biogas production

The tested samples showed monophasic curves of accumulated biogas production. After a steep increase, biogas production decreased resulting in a plateau of the cumulative curve. The maximum biogas rate was achieved in the first week of digestion experiment (Figs 1, & 2). More than 90% of the biogas yields were obtained between first and second week of anaerobic digestion. Biogas production using CS and MC showed a linear curve with progressive increase in biogas production with time (Figs. 1 & 2). The organic dry matter biogas production are as shown in Figures 1 & 2. The figures give the results from the duplicates of the substrate.

3.3 Co-Digestions of Cattle Slurry with Maize Cob

Figures 1- 2 showed the results obtained from the batch co-digestion of cattle slurry with maize cob at mesophilic temperature (37^{o}C). The biogas yields of mono digestions of cattle slurry and maize cobs were found to be 441.33 and 552.53 l_N/kg_{oDM} respectively with corresponding methane yields of 296.50 and 349.78 l_NCH_4/kg_{oDM} respectively. The biogas yields (oDM) of cattle dung co-digested with maize cob at ratios 3:1, 1:1 and 1:3 were found to be 453.38, 417.30 and 428.92 l_N/kg_{oDM} (Figs. 1 & 2). The corresponding methane yields (oDM) were respectively found to be 334.18, 323.63 and 323.27 l_NCH_4/kg_{oDM} when experimented at mesophilic temperatures. Since the experiments was terminated immediately the gas production was not more than 1% of the cumulative yields from the beginning of the experiment up to this time, the results of the predictions of the yields if the experiment had been allowed to proceed showed tremendous increase in the yield using table curve computer software along with the Hill kinetic equation. For instance, at 100% mono digestions of cattle slurry and maize cob, biogas and methane yields of 452.31/698.03 l_N/kgoDM and 330.36/450.57 l_NCH_4/kg_{oDM}

Results showed that co-digesting cattle dung and maize cob at ratio 3:1 gave the highest biogas yields (453.38 l_N/kg_{oDM}) when compared to 417.30 and 428.92 l_N/kg_{oDM} obtained at ratios 1:1 and 1:3 respectively. The reason for this is that higher mixing ratios meant higher quantity of maize cobs in the mixture which also implied increased lignin content and this made digestion activities to be more difficult for the microorganisms. The C/N ratio of maize cob (25:1) which fell within the recommended range for optimum biogas production must have also influenced the yields recorded.

Co-digestion of cow slurry with maize cob showed significant difference between the yields at 95% level of significant ($P<0.05$). Thus, co-digestion of cattle dung with maize cobs showed increase in the yields both from fresh mass and the organic dry matter contents of the selected substrates. The results obtained in this co-digestion (cattle dung with maize cob) agreed with the results of previous researches that co-digestion aids biogas and methane yields (Callaghan *et al*., 1999; Umetsu *et al*., 2006; Murto *et al*., 2004). Methane concentrations of 73.71, 77.55 and 75.37% were also obtained at CS: MC combinations of 3:1, 1:1 and 1:3 respectively. Figure 3 shows the effect of co-digestion at different volatile solid constituents of the selected substrates on biogas and methane yields. Increase in the volatile solid percent of maize cob resulted into corresponding gradual increase in biogas and methane yields. The increases are represented by the simple linear equations (equations 12 & 13) which can be used to predict yields at different volatile concentration (%) of the maize cob.

For biogas yields;

$$y = 0.7915x + 419.11 \quad (12)$$

For methane (CH_4) yields;

$$y = 0.3989x + 305.11 \quad (13)$$

Conclusion

The study has shown that co-digesting cattle slurry with maize cob at different ratios results into an increase in both biogas and methane yields. The study has also revealed that co-digesting CS with MC at ratio 3:1 is optimum for biogas production.

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Plate 1: Experimental set up for batch digestion

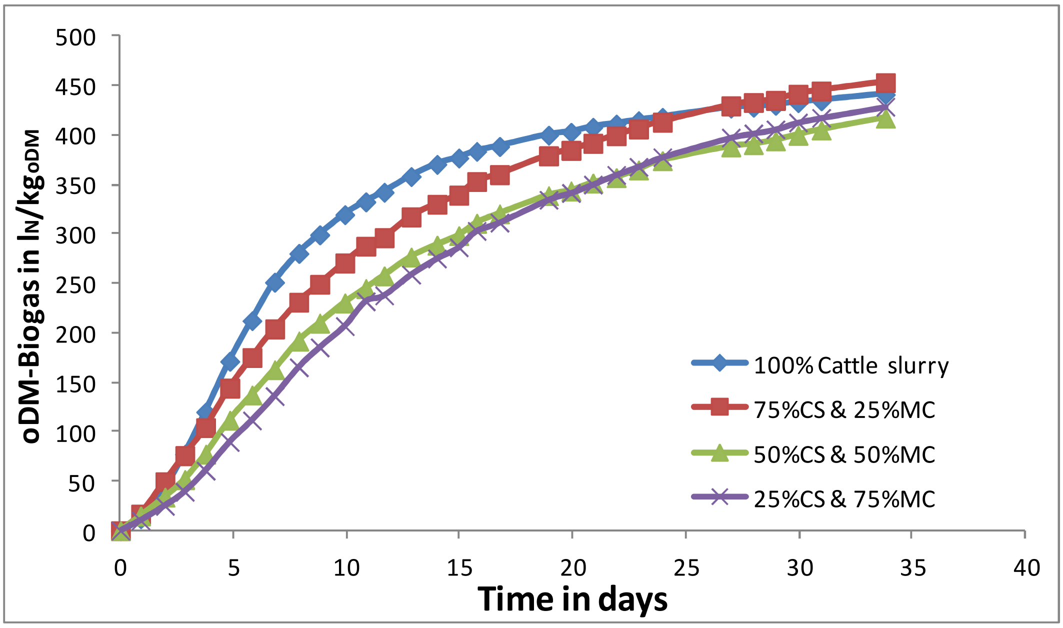

Figure 1: oDM biogas yields of cattle slurry co-digested with maize-cob

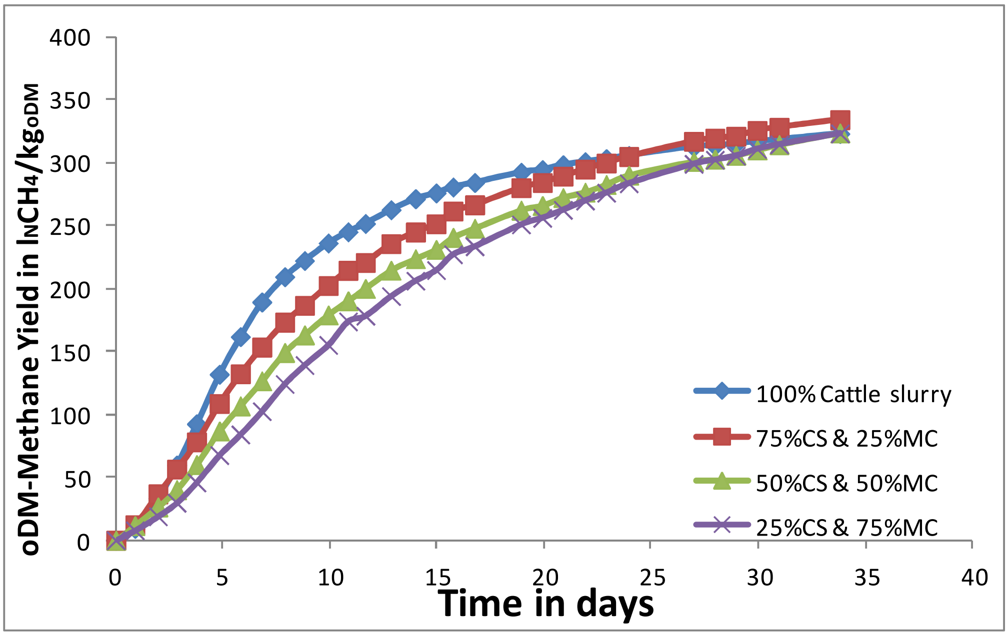

Figure 2: oDM methane yields of cattle slurry co-digested with maize-cob at 37^{o}C

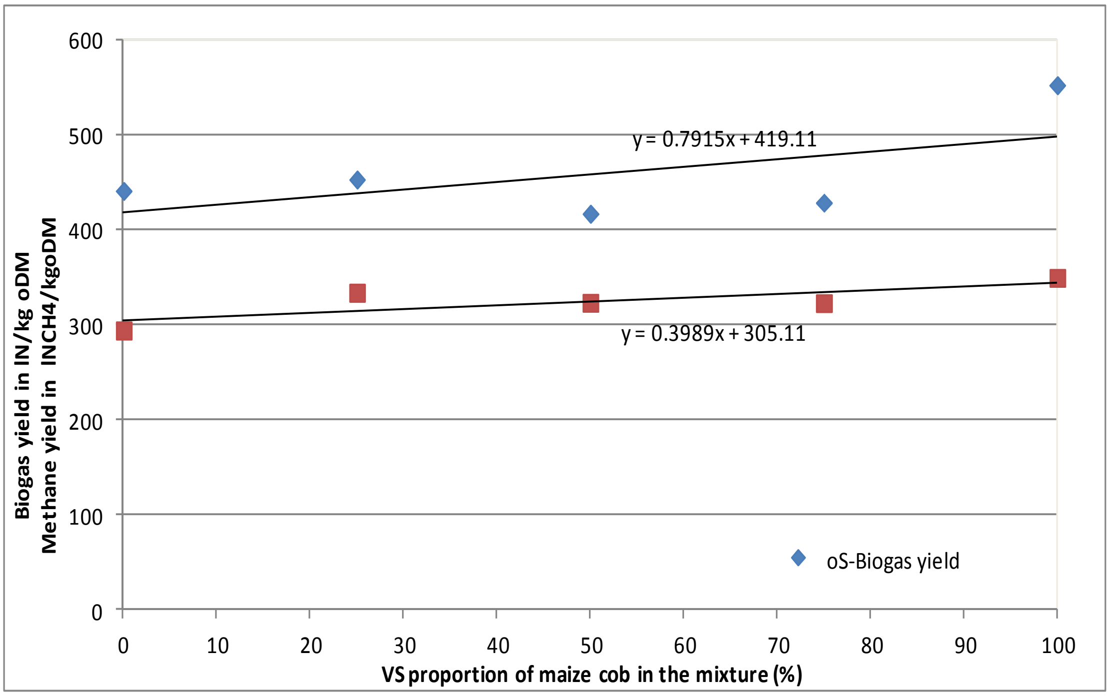

Figure 3: Co-digestion of cattle slurry with maize cob

Table 1: Chemical properties of substrates

Parameter	Analysis	
	Cattle Slurry	Maize Cob
Dry Matter, DM (105°C)-%	11.77	36.10
Organic Dry Matter (oDM, %DM)	84.05	97.30
Organic Dry Matter (%FM)	9.89	35.13
NH_4-N (g/kgFM)	1.22	<2
Crude Fibre (%DM)	26.75	28.32
Fat (% DM)	-	1.14
Potassium (% DM)	2.05	1.27
Ethanol (g/l)	0.12	<0.04
Propanol	<0.04	<0.04
Total Acetic Acid	0.88	8.12
C/N ratio	*19:1	**25:1

(*Zhang *et al.*, 2012, **Singh *et al.*, 2009)