EFFECTS OF CO-DIGESTING SWINE MANURE WITH CHICKEN MANURE ON BIOGAS PRODUCTION

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ABSTRACT

Swine manure (SM) was co-digested with chicken manure (CM) with a view to optimizing biogas production. Five mixtures of SM and CM at ratios of SM/CM 0:1 (CM only), 3:7, 1:1, 7:3 and 1:0 (SM only) (w/w dry basis) were digested in batch-type anaerobic digesters for 63 days. The results showed that co-digestion had significant (p 0.05) effect on the substrate temperature, pH and biogas production. The mean substrate temperature and pH during digestion were 28.5 ± 2.5 °C and 6.80 ± 0.55, respectively. Biogas production from mixture ratios (MRs) 3:7, 1:1, 7:3 and 1:0 stopped on the 32nd, 61st, 35th and 33rd day, respectively, suggesting completion or inhibition of the digestion process. The individual manures, MRs 0:1 and 1:0 produced 0.52 and 0.38 L kg^{-1} VS fed day^{-1}, respectively. MR 3:7 produced 61.5% and 47.4% lower than MRs 0:1 and 1:0, respectively. MR 1:1 produced 69.2% and 131.6% higher than MRs 0:1 and 1:0, respectively. MR 7:3 produced 21.2% lower than MR 0:1 and 7.89% higher than MR 1:0. It can be inferred from the results that anaerobic digestion of mixture of SM and CM at ratio 1:1 (w/w dry basis) appeared to be the optimum for improving biogas production.

Keywords: Co-digestion, Biogas, Swine manure, Chicken manure, Mixture ratio

INTRODUCTION

One of the most critical challenges facing Nigeria today is that of the alarming rate of depletion of traditional sources of energy, largely fuel-wood and charcoal, which together command the largest share of energy used. This has resulted in soil erosion, degradation of the land, reduced agricultural productivity, and potentially serious ecological change (Adegbulugbe and Akinbami, 1995). Therefore, the need for exploring and exploiting new sources of energy, which are renewable as well as eco-friendly, is a necessity. One of such energy is biogas, a methane rich biofuel, produced from anaerobic degradation of organic substrates (animal manures, municipal wastes, plant residues, industrial wastes, etc). Swine and poultry manures, which have become environmental concern in Nigeria due to increased swine and poultry farming, have been identified as suitable feedstocks for biogas production. Anaerobic digestion of these manures alone (Adewumi, 1995; Callaghan et al., 1999; Itodo and Awulu, 1999; Anozie et al., 2005; Ojolo et al., 2007; Rao et al., 2011) and co-digestion with other organic materials (Magbanua Jr et al., 2001; Gelegenis et al., 2007a,b; Kasisira and Muyiiya, 2009; Wu et al., 2010; Riano et al., 2011; Xie et al., 2011) have been extensively studied. The results from these studies have shown that the manures have high potentials for biogas production to supplement wood as an energy source for cooking and lighting and that co-digestion has improved biogas production in most cases. However, poultry manure produces more biogas than swine manure and cow dung (Adewumi, 1995; Callaghan et al., 1999; Itodo and Awulu, 1999; Ojolo et al., 2007) because of its high nitrogen content and high biodigestibility (Odeyemi, 1982). Due to these positive properties of poultry manure, the manure has been used to enhance digestion of and biogas production from various low-nitrogenous organic materials (Magbanua Jr et al., 2001; Misi and Forster, 2001; Gelegenis et al., 2007a,b). In spite of the extensive studies, information on the co-digestion of swine manure with high biogas producing poultry manure, specifically, at different ratios with a view to boosting the biogas production capability of swine manure is still sketchy. Therefore, the objectives of the study were to determine: the effect of mixture ratio (MR) of swine and chicken manures on anaerobic digestion; and MR that will produce the highest biogas yield.

MATERIALS AND METHODS

The anaerobic digestion experiment was carried out under an ambient temperature of 29.6 ± 3.4 °C in a laboratory at the Department of Agricultural and Environmental Engineering, Obafemi Awolowo University, Nigeria. The materials used for this study were fresh swine and chicken manures, both collected from the University Teaching and Research Farm.

The biogas production of the SM-CM mixtures were examined at five MRs (w/w dry weight basis) 0:1 (CM only), 3:7, 1:1, 7:3 and 1:0 (SM only) in 25 L batch-type digesters adapted using rectangular plastic containers (Plate 1). Each digester had drain plug fitted at the base through which samples were collected for pH analysis. Also, a thermometer was fitted to each digester for substrate temperature measurement. Water tanks and water collector tanks were adapted using rectangular 10 and 5 L plastic containers, respectively. The digesters, water tanks and water collectors were inter-connected using rubber hoses with cork fitted tightly to prevent gas and water leakage. Each mixture was diluted to 8% TS, as recommended by Zennaki et al. (1996), agitated vigorously and screened using a 6 mm plastic mesh to remove gross solids. The digesters were loaded once during the experiment to 70% of the capacity with the substrates. The daily biogas production was measured by water displacement method. Each treatment was replicated thrice. The digesters were manually agitated once daily to ensure intimate contact between micro-organisms and the substrates. The substrates were digested for 63 days during which ambient and substrates temperatures and biogas production were measured daily, while pH was measured fortnightly.

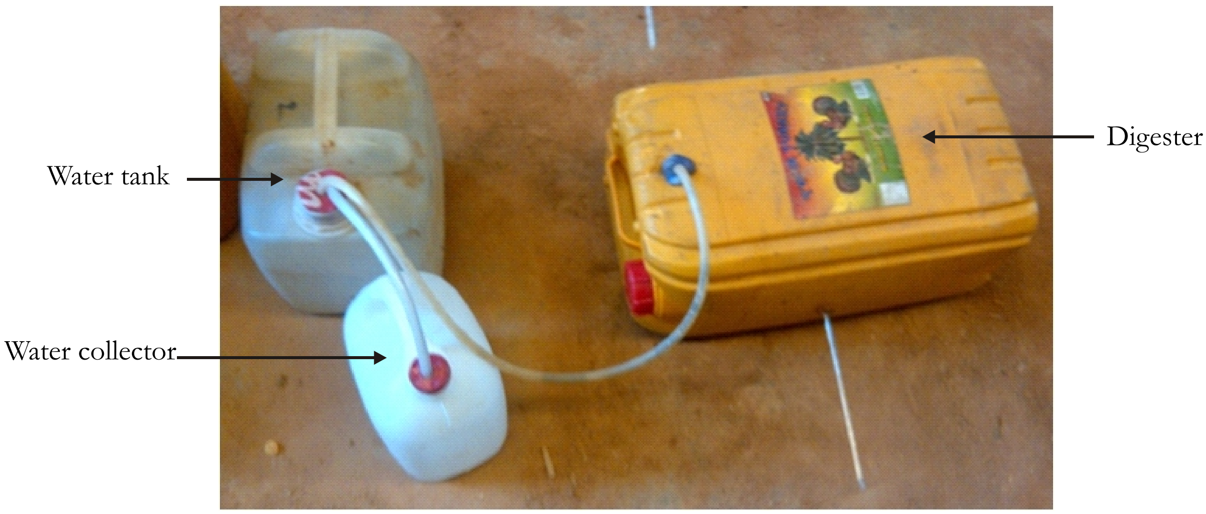

Plate 1. The digester set up

Analytical methods

Samples from the manures were analysed at 105 °C dry weight basis for: total solids (TS) content (drying at 105 °C for 24 h); volatile solids (VS) content (ashing of TS at 550 °C for 5 h in a muffle furnace); total nitrogen (TN) content (regular-Kjeldahl method; (Bremner, 1996)); pH (1:10 w/v sample:water extract, using a pH meter, Model 8000). The total carbon (TC) content was estimated from the ash content according to the formula (Mercer and Rose, 1968):

$$TC\,(\%) \quad [100 \quad Ash\,(\%)]/1.8$$

The initial carbon to nitrogen (C:N) ratio of each mixture was calculated from the estimated TC and TN concentrations of the mixture. The initial properties are summarized in Table 1.

Statistical analyses

The effects of MR on substrate temperature, pH and biogas production were analysed by subjecting the data collected to one-way analysis of variance (ANOVA). Duncan's Multiple Range Test was used to separate means that were significant at p 0.05. Pair-wise correlation of parameters was carried out to determine significant relationships. All analyses were performed using the Statistical Analysis System software (SAS, 2002).

RESULTS AND DISCUSSION

The initial C:N ratios of the manure mixtures, which increased as the level of SM in the mixtures decreased, ranged from 17.9:1 to 19.8:1 (Table 1). The results of the ANOVA showed that the effect of MR was significant (p = 0.05) on digester temperature, pH and biogas production (Table 2).

MR	Properties*				
	pH	VS (%)	TC (%)	TN (%)	C:N ratio
0:1	6.98	72.8	40.4	2.04	19.8:1
3:7	6.64	68.6	38.1	1.97	19.3:1
1:1	6.70	65.9	36.6	1.93	19.0:1
7:3	6.79	63.2	35.1	1.89	18.6:1
1:0	6.25	59.0	32.8	1.83	17.9:1

*Mean values are shown (n = 3).

Table 2. ANOVA Results Showing the Effect of Manure Mixing on the Parameters

Parameter	Source	DF	SS	MS	F-value	Pr>F
Temperature	Treatment	4	2.157	0.539	140.374	<0.0001
	Error	10	0.038	0.004		
pH	Treatment	4	0.219	0.055	99.484	<0.0001
	Error	10	0.006	0.001		
Biogas production	Treatment	4	0.753	0.188	73.667	<0.0001
	Error	10	0.026	0.003		

DF, degrees of freedom; SS, sum of squares; MS, mean of squares; F, critical value; Pr, probability value.

Effect on substrate temperature

The mean substrate temperature during digestion was 28.5 ± 2.5 °C. This temperature was within the mesophilic range of 25-35 °C considered optimal for the support of biological-reaction rates (Tchobanoglous et al., 2003). It was observed that MR 0:1 and 1:1, which had lower average temperatures (Table 3), had longer digestion times and significant (p 0.05) correlation between substrate temperature and biogas production (Table 4). The variation of substrate temperature with time, as shown in Fig. 1, indicated that temperatures of MRs 3:7 and 7:3 increased gradually, while MRs 1:0, 0:1 and 1:1 had fluctuations of ±0.50, ±1.03 °C and ±1.50 °C, respectively during the digestion period. The non-significant (p > 0.05) correlations between ambient and substrate temperatures (Table 4) showed that there was no heat exchange through the digesters wall. Also, there was no significant (p > 0.05) correlation between substrate temperature and pH in any of the treatments (Table 4).

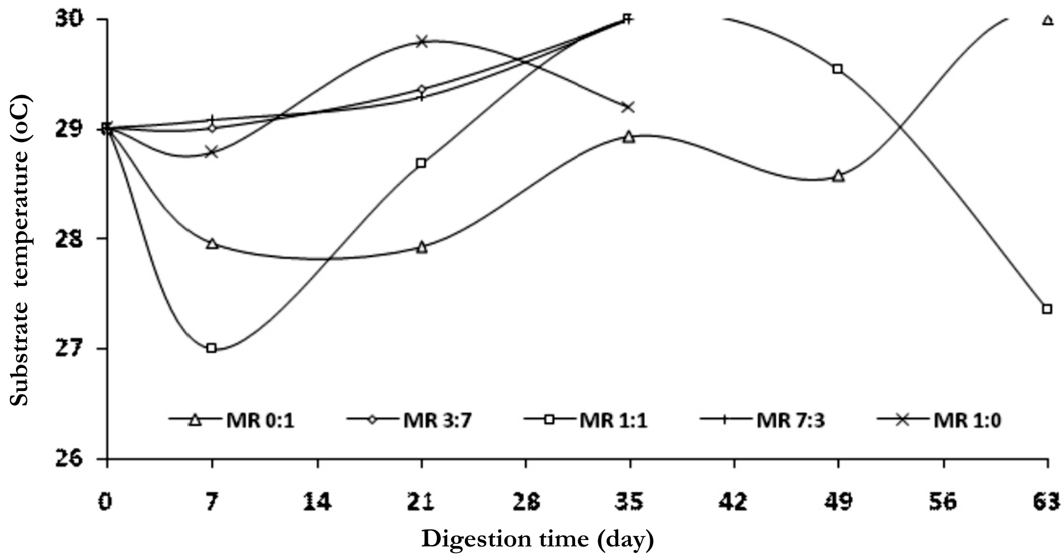

Figure 1 Variation of Substrate Temperature during Digestion.

Table 3. Significant Means Separation using the Duncan's Multiple Range Tests

MR	Temperature (°C)	pH	Biogas (L kg^{-1} VS fed day^{-1})
0:1	28.4^{d}	6.87^{b}	0.52^{a}
3:7	29.4^{a}	6.98^{a}	0.20^{c}
1:1	28.8^{c}	6.65^{c}	0.88^{d}
7:3	29.4^{a}	6.98^{a}	0.41^{b}
1:0	29.2^{b}	6.87^{b}	0.38^{e}

Superscripts with the same letter are not statistically different at p 0.05.

Table 4. *R*-squared Values From Pair-wise Correlation of Parameters

MR	Pair-wise correlated parameters			
	AT/ST	ST/BP	pH/BP	pH/ST
0:1	0.082	0.243^{a}	0.06	0.076
3:7	0.054	0.038	0.846^{a}	0.123
1:1	0.086	0.233^{a}	0.083	0.155
7:3	0.061	0.004	0.466	0.005
1:0	0.014	0.085	0.615	0.665

[a] Values significant at p 0.05.
AT: ambient temperature; ST: substrate temperature; BP: biogas production.

Effect on substrate pH

The range of substrates pH during digestion (6.25-6.98) was within 6-8 considered suitable for bacteria involved in anaerobic digestion. The pH variation was characterized by increase and decrease in pH values (Fig. 2) of the treatments. According to Macias-Corral et al. (2008), decrease in pH could be attributed to hydrolysis of the easily degradable fraction of the manures and conversion to volatile fatty acids (VFA), while the increase could be attributed to subsequent transfer and consumption of VFA by methanogenesis. The pH fluctuations were highest and least in MR 1:0 (±0.54) and MR 3:7 (±0.33), respectively. The pH of MR 0:1 continued to increase throughout the experiment after a temporary decrease during the first week. MRs 3:7, 7:3 and 1:0 had the same pattern of variation during the experiment.

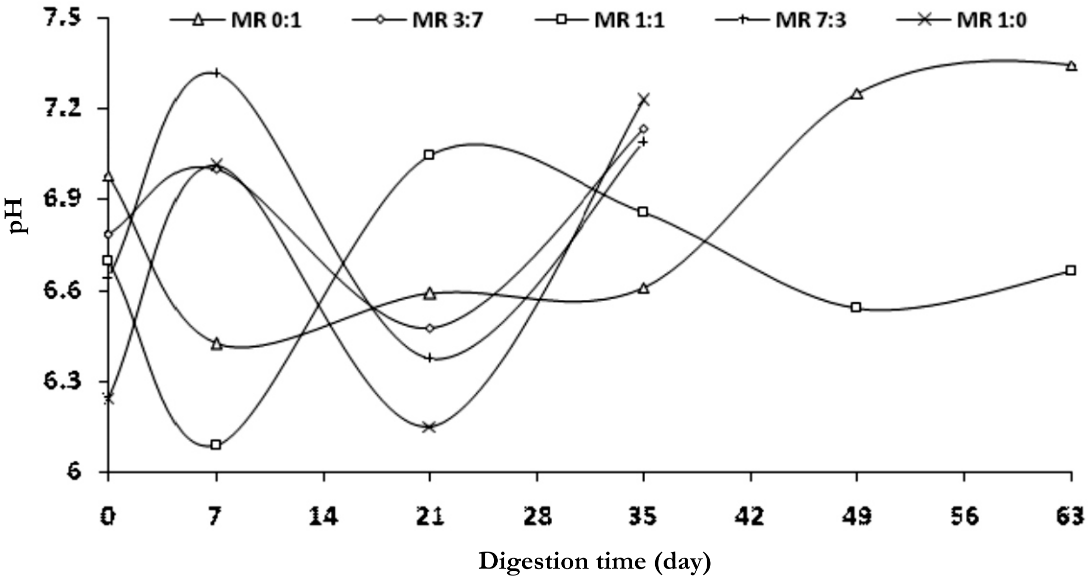

Figure 2 Variation of pH during Digestion.

Biogas production

Biogas production rate and total production are a function of the substrates' organic matter content and biodegradability (Macias-Corral et al., 2008). Daily production and cumulative production were measured for each treatment. The results of daily production are presented in Fig. 3. The MRs (except MR 1:1) started biogas production within 24 h. The one day lag experienced by MR 1:1 could be attributed to the time needed by the microbial flora in the equal-weighted SM and CM to acclimatize to the altered environmental conditions. The daily production of each MR fluctuated repeatedly and peaked at different days during digestion. The differences in peak periods were attributed to the differences in organic matter content and the degree of biodigestibility of the manure mixtures (Odeyemi, 1982). Some days of non-production during digestion were recorded in all the treatments. The total values showed that MRs 0:1, 3:7, 1:1, 7:3 and 1:0 had 5, 4, 11, 8 and 5 days, respectively of no biogas production. This may probably be as a result of methanogens undergoing a methamorphic growth process by consuming methane precursors produced from the initial activity (Lalitha et al., 1994). Productions from MRs 3:7, 1:1, 7:3 and 1:0 stopped on the 32nd, 61st, 35th and 33rd day, respectively, while MR 0:1 produced throughout the experiment. The stoppage of production suggested completion of the digestion process or process breakdown possibly as a result of methane inhibitors in the manure(s). Average values showed that biogas production was highest during the first week in MRs 0:1, 3:7, 7:3 and 1:0, while MR 1:1 recorded highest production during the third week. After the peaks, production dropped gradually to completion, except in MR 0:1 which had another increase in production during week 7.

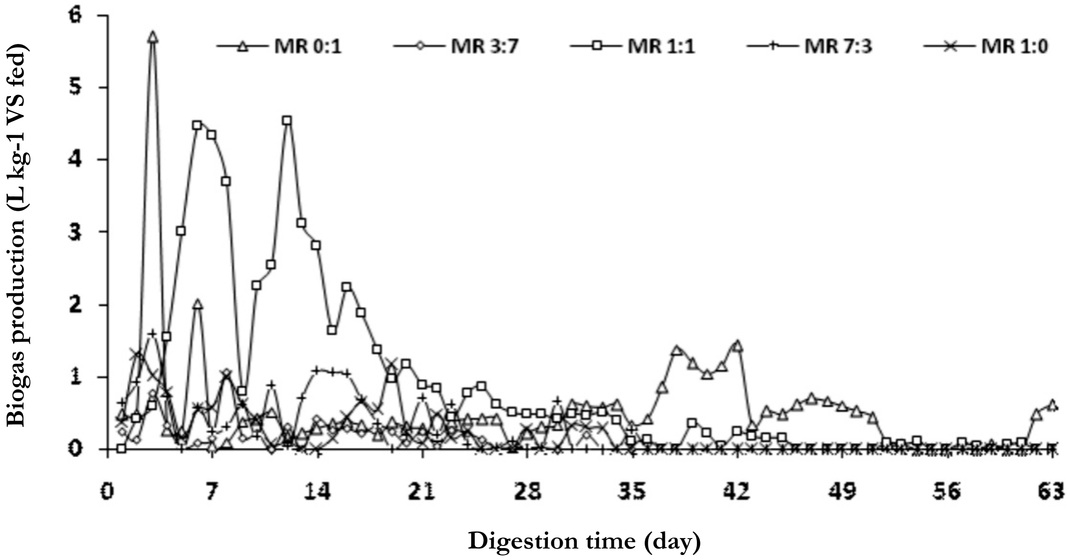

Figure 3 Variation of Daily Biogas Production during Digestion.

The cumulative biogas production (Fig. 4) showed that MRs 1:1 and 3:7 produced the highest and least quantities of biogas during the experiment. In terms of the individual manures, the average daily biogas production from MR 0:1 (0.52 L kg^{-1} VS fed day^{-1}) was higher than that from MR 1:0 (0.38 L kg^{-1} VS fed day^{-1}) (Table 3). This finding was in conformity with previous anaerobic digestion studies (Adewumi, 1995; Itodo and Awulu, 1999; Ojolo et al., 2007) and was attributed to high biodigestibility of poultry manure (Odeyemi, 1982). It was observed that MRs 0:1 and 1:1, which had lower digester temperatures had higher biogas production. Angelidaki and Ahring (1994) had similar observation that temperature reduction resulted in an increase of biogas yield. MR 1:1 produced the highest average daily biogas (0.88 L kg^{-1} VS fed day^{-1}), which was 69.2% and 131.6% higher than MRs 0:1 and 1:0, respectively. MR 7:3 produced 0.41 L kg^{-1} VS fed day^{-1}, which was 21.2% lower than MR 0:1 and 7.89% higher than MR 1:0. MR 3:7 produced the lowest average daily biogas (0.20 L kg^{-1} VS fed day^{-1}), which was 61.5% and 47.4% lower than MRs 0:1 and 1:0, respectively. Disparities in gas productions from animal manures have been attributed to various factors of (Bryant et al., 1971; Odeyemi, 1982; Coombs, 1990): manure (C:N ratio, chemical and physical composition digestibility of lignocellulosic materials and presence of inhibitors), animal (digestive physiology) and diet (nutrient composition).

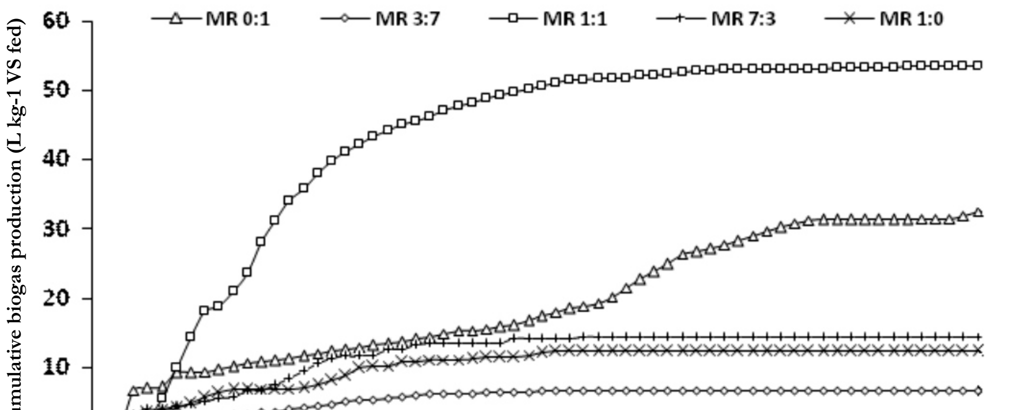

Figure 4 Cumulative Biogas Production during Digestion.

CONCLUSIONS

Co-digestion of SM and CM has shown a significant effect on anaerobic digestion. The results showed that MR had significant (*p* 0.05) effect on substrate temperature, pH and biogas production. The mean substrate temperature and pH during digestion were 28.5 ± 2.5 °C and 6.80 ± 0.55, respectively. MRs 0:1 (CM only) and 1:0 (SM only) produced average daily biogas of 0.52 and 0.38 L kg^{-1} VS fed day^{-1}, respectively. MR 1:1 appeared to be the optimum as it produced the highest average daily biogas, which was 69.2% and 131.6% higher than productions from MRs 0:1 and 1:0, respectively.

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