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Effect of mixing ratio of slurry on biogas productivity of major farm animal waste types

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ABSTRACT
Objective: To investigate the effect of mixing ratio of slurry on biogas productivity of wastes from poultry birds, pigs and cattle.
Methodology and results: The investigation was carried out using 9 Nos. 220-litre batch type anaerobic digesters designed to remove CO_2, H_2S and other soluble gasses from the system. Freshly voided poultry, piggery, and cattle wastes were collected from livestock farms at the Institute of Agricultural Research and Training (IAR&T), Moor Plantation, Ibadan, Nigeria. After being totally freed of foreign matter, the samples were well stirred and digested in a 3x3 factorial experiment using a retention period of 30 days and within the mesophilic temperature range. The waste: water mixing ratios of slurry used were 1:1, 2:1 and 3:1 by mass. Three replicates were used for each ratio. Two hundred gram samples of each animal waste type were obtained before and after experimentation and analysed for chemical constitution. All the readings of the biogas yield were analysed using the Duncan Multiple Range Test (DMRT). Biogas yield was significantly ($p < 0.05$) influenced by the various factors of animal waste ($F=86.40$, $P< 0.05$), different water mixing rates ($F=212.76$, $P< 0.05$) and the interactions of both factors ($F=45.91$, $P< 0.05$). Therefore, biogas yield was influenced by variations in the mixing ratios as well as the waste types used. The 1:1 mixing ratio of slurry resulted in biogas productions of 20.8, 28.1, and 15.6 l/kgTS for poultry, piggery and cattle wastes respectively. The 2:1 ratio resulted in 40.3, 61.2 and 35.0l/kgTS while the 3:1 ratio produced 131.9, 117.0 and 29.8l/kgTS of biogas respectively. Therefore an increasing trend was observed in biogas production as mixing ratio changed from 1:1 to 3:1. For cattle waste however, production decreased from ratio 2:1 to ratio 3:1. The N, P, K values were highest for poultry waste (3.6, 2.1, and 1.4% respectively) and least for cattle waste (2.2, 0.6, 0.5% respectively). Organic carbon was highest for cattle waste (53.9%) and least for poultry waste (38.9%). Reduction in C/N ratio for each experiment ranged from 1.1 to 1.9%.
Conclusion and application of findings: This study found that for poultry and piggery wastes, slurries mixed in ratios 3:1 waste:water produced more biogas than those of 2:1 and 1:1 ratios. For cattle waste, the 2:1 mixing ratio produced the most biogas. This paper therefore recommends a livestock wastes: water mixing ratio of 3:1 for poultry and piggery slurries, and 2:1 for cattle slurry for maximum biogas production from methane-generating systems, given 30% TS content.

Key words: Anaerobic digestion, biogas, cattle waste, piggery waste, poultry waste.

INTRODUCTION

Scientific interest and efforts in researching into biogas production technology are still relevant because of the often very high costs of energy supply worldwide. Another reason for their relevance is the fact that the rampant use of firewood for domestic cooking in low income countries invariably results in the destruction of forests which is harmful to the environment. Also, the use of firewood, kerosene and charcoal in households has adverse effects on human health (Adelekan & Adelekan, 2004). Furthermore, using waste biomass to produce energy can reduce the use of fossil fuels, reduce greenhouse gas emissions and reduce pollution and waste management problems (Vetter *et al.,* 1990; Marshall, 2007; Inderwildi and King, 2009). EEA (2006) pointed out that by 2020, the equivalent of 19 million tonnes of oil will be available from biomass, of which 46% will be from biowastes mainly municipal solid wastes, agricultural residues, farm waste and other biodegradable waste streams.

The objective of the research work being reported in this paper was to investigate the effect of mixing ratio of slurry on biogas productivity of wastes from poultry birds, pigs and cattle. Biomass represents a continuously renewable potential source of methane and thus offers a partial solution to the eventual prospects of fossil fuel depletion. In addition, biomass can be economically converted to biogas at a variety of scales and thus can be tailored to supply local, regional and nationwide biogas needs.

It has been discovered that, under aerobic conditions, living plants also produce methane which is significantly larger in volume than that produced by dead plants. Although this does not increase global warming because of the carbon cycle (Keppler *et al.,* 2006), it is not readily recoverable for economic purposes. However, the methane which is recoverable for the direct production of energy is from dead plants and other dead biomass under anaerobic conditions. Biogas is a flammable gas produced by microbes when organic materials are fermented in a certain range of temperatures, moisture contents, and acidities, under air–tight conditions. Anaerobic digestion is a process through which organic materials are decomposed by bacteria in the absence of air to produce biogas. The digestion process itself starts with the bacterial hydrolysis of the biomass so as to break down carbohydrates and other insoluble organic polymers. After the chemical break down, various kinds of bacteria convert the materials into different gases and organic acids in several stages (Ciborowski, 2004). Methanogenic bacteria finally convert these products into methane and carbon dioxide (Fergusen and Mah, 2006; Anaerobic Digestion Reference Sheet, 2007). UNDP (1997) stated that anaerobic digestion facilities constitute one of the most useful decentralized sources of energy supply and they are less capital intensive than conventional power plants.

Many publications have pointed out that simple, home and farm-based anaerobic digestion systems have the potential for supplying cheap, low cost energy for cooking and lighting in developing countries (Doelle, 2001; Friends of the Earth, 2004; Cardiff University, 2005). Many developing nations meet significant amounts of their energy needs through biogas particularly in the rural areas. The biogas support program in Nepal has installed over 150,000 biogas plants in the rural areas (AEPCNEPAL, 2009) while the biogas program in Vietnam has led to the installation of more than 20,000 plants throughout the country (SNV, 2009). Also, in Rwanda, the Kigali Institute of Science and Technology has developed and installed several large-scale biogas plants at prisons to treat sewage and provide biogas for cooking (KIST, 2009). Even in developed countries, significant potential for biogas use still exists. For example in the United Kingdom, biogas is estimated to have the potential to replace about 17% of vehicle fuel (Claverton Energy Conference, 2008). In Sweden, a biogas-powered train has been in service since 2005 (Svenskbiogas, 2005).

Options for biomass exploitation include plant materials and livestock wastes mostly. Several researchers have reported biogas production from various materials including pigeon droppings, (Aliyu *et al*, 1995); other bulk organic wastes (Kovacs *et al*, 1995), water hyacinth, *Eichhornia* species (Bamgboye and Abayomi, 2000); camel and donkey dung (Dangoggo *et al*, 2004) and other farm animal wastes (Adelekan *et al*, 2009). Specifically in the case of Nigeria where this research was conducted, reported values of animal waste production range from 144 million tonnes/year (Energy Commission of Nigeria, 1998) to 285.1 million tonnes/year (Adelekan, 2002). These figures suggest that on a daily basis, Nigeria's farm animals generate huge quantities of manure which can be anaerobically digested to produce methane gas. While research interest into the use of animal waste to produce methane is increasing, it is important to investigate the methane productivity of individual manure types so as to provide the most optimal mixing ratios of the various slurries, and also ascertain the manner in which these ratios influence productivity.

Ultimate methane yields from biomass are influenced principally by the biodegradability of the organic components. The more putrescible the biomass, the higher is the gas yield from the system (Wis, 2009). Each anaerobic environment may differ in the types of bacteria involved in methanogenesis, depending on differing factors such as type of substrate, retention time, temperature, pH, and fluctuations in environmental parameter. Although some general properties such as temperature and solar radiation are similar from one environment to another, each environment may have its own unique population of bacteria, and associated microbial activities. Key operating factors which have a direct influence on the level and efficiency of biogas production include volatile solids loading rate, digester temperature, hydraulic retention time, pH and carbon: nitrogen ratio (Vetter *et al*., 1990).

Song *et al.,* (2004) pointed out that there are two conventional operational temperature levels for anaerobic digesters and these are determined by the species of methanogens inside the digester. These are mesophilic (i.e. 20-45^{0}C) with optimal performance around 37-41^{0}C, and thermophilic which takes place at higher temperatures of up to 70^{0}C, although optimal digester performance is around 50-52^{0}C. According to Martin (2007) the methanogens involved in the biological process of methanogenesis which is the terminal stage of anaerobic digestion require a neutral or mildly alkaline environment, as a too acidic or too alkaline environment would be detrimental. They further pointed out that a pH between 6.5 and 8 is best for methanogenesis. The pH value of the slurry in a digester depends on the carbon dioxide content in the digester, the determining factor being the density of the acids. The hydraulic retention time (HTR) in anaerobic digesters is determined by calculating the number of days required for displacement of the fluid volume of the culture. The retention time is also dependent on all the factors discussed above. Generally a retention time of between 30 and 45 days and in some cases 60 days is enough for substantial gas production (Clanton *et al.*, 1985; Carcelon and Clark, 2002).

The carbon: nitrogen (C/N) ratio expresses the relationship between the quantity of carbon and nitrogen present in organic materials. Materials with different C/N ratios differ widely in their yield of biogas. The ideal C/N ratio for anaerobic biodigestion is between 20:1 and 30:1 (Marchaim, 1992). If C/N ratio is higher than that range, biogas production will be low, because the nitrogen content of the feed material will be consumed rapidly by methanogenic bacteria for meeting their protein requirements rather than reacting on the carbon in the material. Materials with high C/N ratio are typically the residues of agricultural plants.

Conversely if C/N ratio is very low, that is outside the ideal range, nitrogen will be liberated and will accumulate in the form of ammonia, which raises the pH value of the slurry in the digester. A pH value higher than 8.5 would be toxic to the methanogenic bacteria in the slurry. The cumulative effect of this is reduced biogas production. Materials having low C/N ratio could be mixed with those having high C/N ratios so as to bring the average C/N ratio of the mixture to a desirable level. Human excreta, duck dung, chicken dung, and goat dung are some of the materials which typically have low C/N ratios (Karki & Dixit, 1984).

MATERIALS AND METHODS

Raw materials and equipment: Freshly voided poultry, piggery, and cattle wastes were collected from livestock farms at the Institute of Agricultural Research and Training (IAR&T), Moor Plantation, Ibadan, Nigeria. Nine 220-litre black-coated, batch type, sheet metal digesters which incorporated a water tank as well as iron sponge and saw dust sealed in a separate cylinder were used in this 3x3 factorial experiment.

Experimentation: Prior to loading into the digester, stones, leaves, waste feed, sticks, and other foreign matter were carefully picked from the wastes which were then properly stirred to break the lumps into finer particles. A 25 kg charge (30%TS) of each waste type was measured and mixed with 25 kg of water in a mixing tank; and stirred for about 20 minutes to ensure sufficient dispersal of the waste particles and achieve slurry of regular consistency. The mixed slurry was then poured into the digester tank and sealed properly to ensure air-tightness. Two other concentrations of ratios 2:1 (50 kg of waste mixed with 25 kg of water) and 3:1 (75 kg of waste mixed with 25 kg of water) were loaded. Three replicates were used for each experiment. All the experiments were subjected to a retention period of 30 days each. All were exposed to ambient temperatures which were within the mesophilic range and none was artificially heated.

The whole arrangements were fully set up on the experimental site, free of any shade to ensure maximum reception of solar radiation. The ambient temperatures of the site were continually monitored and measured daily. The arrangement was vigorously shaken twice daily, at 7.00am in the morning and 7.00pm in the evening and biogas production was measured at 12.00 noon throughout the 30-day retention period used for every experiment. Biogas samples were obtained at the beginning, and towards the end of the detention period. Biogas quality was measured using a gas detector. Volume measurements of biogas produced were done by water displacement.

The experiment reported in this present study is part of a wider set of biogas production experiments which were conducted in the months of February to May, 2008. Energy to run the experiments came entirely from solar radiation. According to Fagbenle (1991), the monthly average daily extraterrestrial solar radiation for Ibadan, Nigeria is as shown in Table 1.

Table 1: Monthly average daily extraterrestrial solar radiation on horizontal surface (KJ/m^2) for Ibadan, Nigeria (Lat 7.43^0N, Long 3.80^0E) (Source: Fagbenle (1991).

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Ave. H_o	31820	34225	36531	37582	37365	36948	37149	37600	37169	35287	32659	31050
H_oAD	31806	34186	36535	37585	37372	36950	37153	37600	37175	35326	32655	31060
Average Day	17	14	15	11	16	11	17	12	17	16	15	11
% Error	-0.04	-0.11	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.11	0.00	0.03
H_o 16	31739	34171	36597	37642	37372	36914	37135	37637	37214	35326	32571	30937
Mean Day	16	16	16	16	16	16	16	16	16	16	16	16
% Error	-0.25	0.43	0.18	0.16	0.02	-0.09	0.04	0.11	0.12	0.11	-0.26	-0.36
H_o Mean	31806	34371	36597	37634	37391	36950	37153	37637	37251	35409	32739	31093
Julian Day	17	16	16	15	15	11	17	16	15	15	14	10
% Error	-0.04	0.43	0.18	0.14	0.07	0.01	0.11	0.11	0.22	0.35	0.25	0.14

H_o = Extraterrestrial solar radiation on a horizontal surface, KJ/m^2.
Ave. H_o = Monthly average daily extraterrestrial solar radiation on a horizontal surface.
H_o AD = Extraterestrial solar radiation on a day (average day) with minimum difference in radiation value from the monthly averaged daily value, KJ/m^2-day
H_o 16 = Extraterestrial solar radiation on the 16^{th} day of each month, KJ/m^2-day.
H_o JD = Extraterestrial solar radiation on the Julian day of each month, KJ/m^2-day.

Chemical analyses: Two hundred gram replicate samples of each manure type were obtained before and after experimentation and taken for laboratory analyses using standard laboratory procedures (AOAC, 1990). The parameters analyzed were pH, temperature, moisture content, total organic carbon, phosphorous, potassium, nitrogen (%), total solids, volatile solids, and C/N ratio.

RESULTS AND DISCUSSIONS

As shown in Table 2, the values of total nitrogen, phosphorous and potassium were found to reduce in the digested sludge. This may be due to loss of some of the elements in solution and evaporation during the experiments. Biochemical processes occurring during digestion cause nitrogen and other elements in the digested sludge to be more accessible for plant utilization. Though some nitrogen and other elements may be lost in the slurry solution; causing their total values in the sludge to reduce, yet their available quantities useful to the plants rise. It is for this reason that digested biomass has been reported to increase agricultural productivity by as much as 30% over farmyard manure.

Biogas yield is significantly ($p < 0.05$) influenced by the various factors of animal waste ($F=86.40$, $P< 0.05$), different water mixing rates ($F=212.76$, $P< 0.05$) and the interactions of both factors ($F=45.91$, $P< 0.05$) (table 3). This implies that biogas yield was determined by variations in the mixing ratios and the type of animal waste used.

Table 2: Chemical analyses of undigested and digested manures (1:1).

Parameters	Undigested Manures			Digested Manures		
	Poultry	Piggery	Cattle	Poultry	Piggery	Cattle
% Organic Carbon	38.94	52.91	53.92	29.27	38.52	49.02
Total Nitrogen	3.56	2.91	2.24	2.36	2.14	2.06
C/N Ratio	10.90	18.20	24.10	11.0	18.0	23.80
%K	1.42	0.88	0.48	0.89	0.93	0.58
%P	2.06	0.96	0.57	1.14	1.02	0.69
%NO_3	0.83	7.02	5.40	0.64	7.56	5.94
Zn (mg/kg)	486	1376	107	362	1094	96
Cu (mg/kg)	82	429	18.70	52	286	12.90
Mn (mg/kg)	638	376	147.6	442	215	133.50
pH	7.20	7.90	8.50	6.70	5.40	7.50
%Na	0.63	0.21	0.84	0.3	0.13	0.23
%Ca	3.04	2.14	0.53	1.89	1.89	0.31
Pb (mg/kg)	25.4	4.7	21.90	14.3	3.1	17.50
%Ash	28.97	8.74	9.29	24.87	6.92	7.68

Table 3: Analysis of variance showing significant effect of main and interaction on biogas yield.

Source	DF	Sum of Squares	Mean Square	F Value	Significance P
REP	2	0.01	0.01	0.00	0.9963
Animal waste	2	317.72	158.86	86.40	0.0001
Water mixture ratio	2	782.40	391.20	212.76	0.0001
Animal waste x Water mixture	4	337.65	84.41	45.91	0.0001
Error	799	1469.13	143.78		
Corrected Total	809	2906.92	1.84		

Mean=0.1.76, CV=7.70, R-square=0.49

The separation of means of biogas yield for various treatments showed no significant difference between piggery and poultry wastes but both are significantly higher than the yield from cattle waste.
The mixtures of piggery waste and poultry waste produced much more biogas than that of cattle waste. Fig 1 shows that piggery and poultry wastes produced significantly higher biogas yield than cattle waste. A significant difference was observed in biogas yields among the three waste mixing ratios. The 3:1 ratio had the highest mean yield while the 1:1 had the least. This is shown in Fig 2. This implies that feed material concentrate level is an important factor in biogas production. The comparison of biogas yield among the three ratios is illustrated in Fig 2. The manner in which these animal waste types and water mixing ratios jointly affect biogas yield are compared in Fig 3.

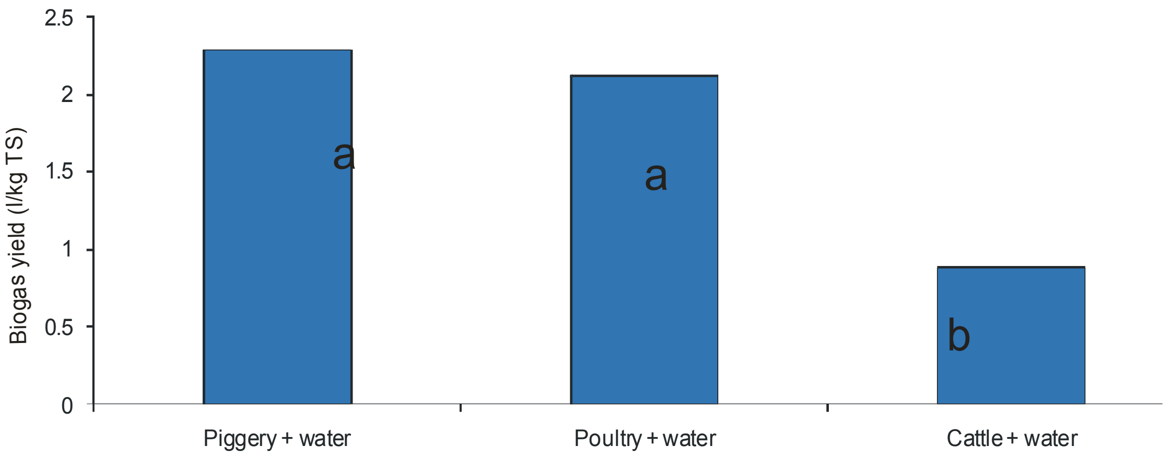

Fig 1: Effect of type of animal waste on biogas yield.

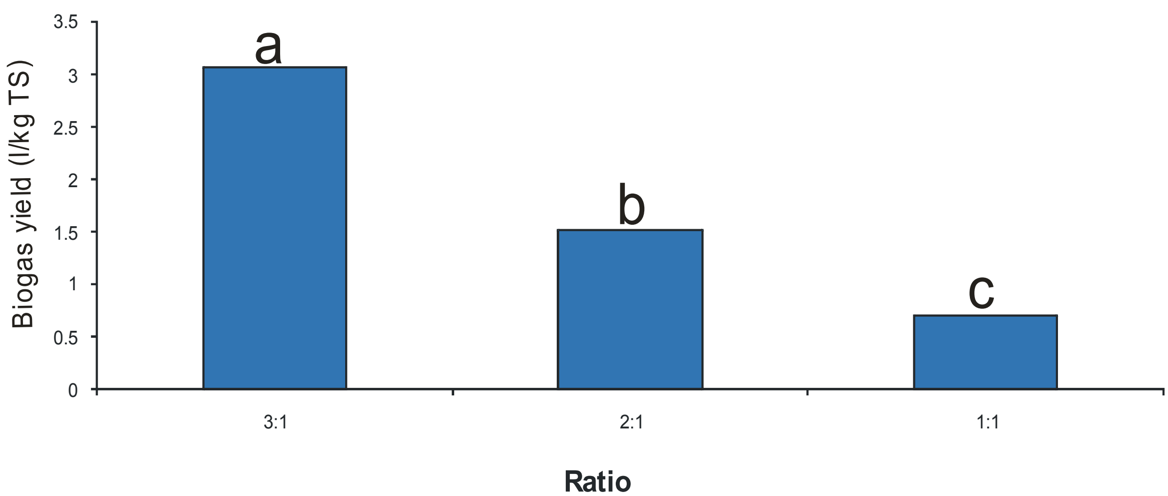

Figure 2: Effect of mixing ratio of waste and water on biogas yield

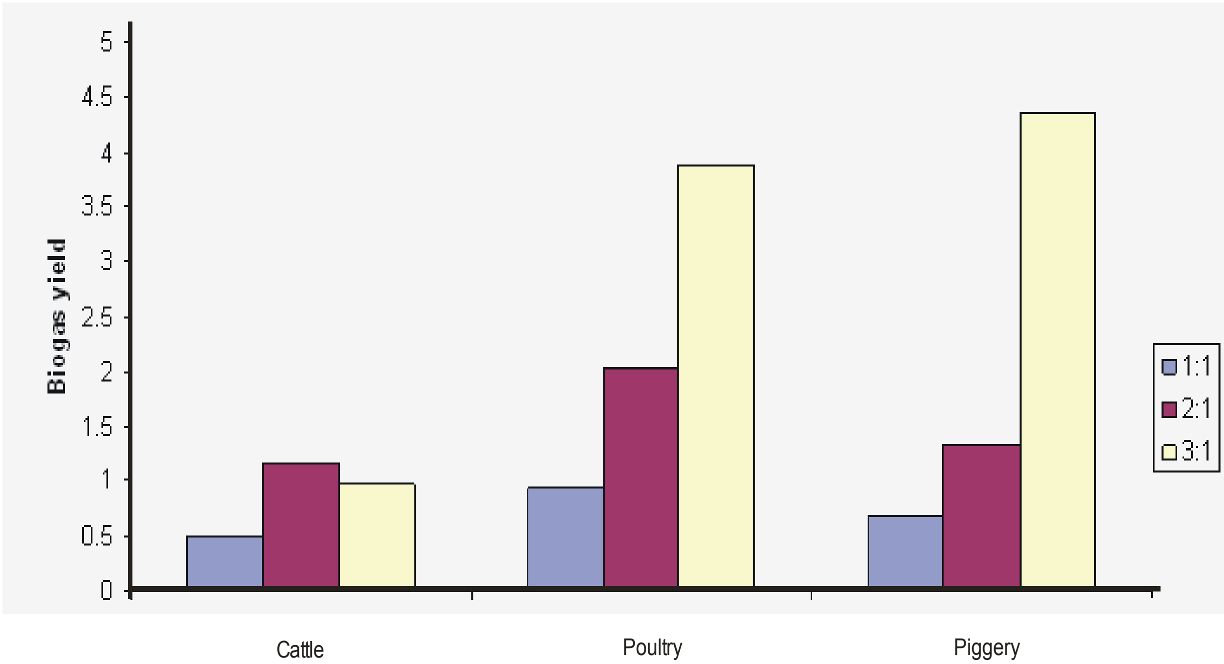

Figure 3: Joint effect of animal waste type and water mixing ratio on biogas yield

Table 4 shows the interactions among the different waste types and water mixing ratios. The highest biogas yields were obtained with piggery and poultry waste while the least were with cattle waste. Also 3:1 ratio produced the highest biogas yield in the cases of poultry and piggery waste; while in the case of cattle waste, 2:1 ratio produced the highest biogas yield. For the 3 waste types, 1:1 mixing ratio produced the least biogas yield.

Table 5 shows summary of cumulative biogas production from the different manure types using the selected ratios. From the results it was observed that piggery manure had the highest cumulative biogas production among all the manure types while cattle manure had the least.

Table 4: Table of interaction among different waste types and water mixing ratios.

Water mixture	Cattle	Poultry	Piggery
1:1	0.51	0.93	0.67
2:1	1.16	2.03	1.33
3:1	0.97	3.88	4.37
SE±	0.47		

Table 5: Summary of cumulative biogas production from piggery, poultry and cattle manures at varying mixing ratios.

Manure Type	Total Solids (%)	Retention Period (Days)	Cumulative Biogas Production (l/kg TS)		
			Ratio 1:1	Ratio 2:1	Ratio 3:1
Poultry	30	30	20.8	40.3	131.9
Piggery	30	30	28.4	61.2	117.0
Cattle	30	30	15.6	35.0	29.8

Furthermore, using a mixing ratio of 3 parts of waste to 1 part of water (w/w) produced higher cumulative gas volumes than using ratios of 2:1 or 1:1 in all cases. Chemical analyses conducted on the fresh and digested wastes, shown in Table 2 revealed that poultry, piggery and cattle manure, respectively, had C/N ratios of 10.8, 18.2 and 24.5. The N, P, K values were highest for poultry waste (3.6, 2.1, 1.4% respectively) and least for cattle waste (2.2, 0.6, 0.5% respectively). Organic carbon was highest for cattle waste (53.9%) and least for poultry waste (38.9%). Reduction in C/N ratio for each experiment ranged from 1.1 to 1.9%. Studies by Karki and Dixit (1984) reported that the best biomass materials which result in highest biogas production have C/N ratios in the range 21 to 28. Cattle manure is well within this range and yet it produced the least volumes of biogas. Piggery is closer to this range than poultry manure which is much lower. This further reinforces the fact that cattle manure does not yield biogas as much as poultry or piggery manure does.

The corresponding best fit curves of biogas yield together with their R^2 values and equations governing the relationships are shown in Figs. 4 to 6. Considerably high square correlation (R^2) values are seen in the graphs for various waste types and also different mixing ratios. The R^2 values showed that considering the detention period, the equations shown on the curves can predict biogas production in the experiment carried out to a high degree of accuracy. From Fig 4, the curves are 79.1, 75.9, and 81.2% accurate for predicting biogas production in poultry, piggery and cattle wastes respectively when mixing ratio 1:1 is used. For 2:1 mixing ratio the values were 91.7, 85.1 and 76.7% respectively for poultry, piggery and cattle wastes (data not shown). In the case of 3:1 mixing ratio, the values are 90.7, 95.5 and 83.8% for the manure types respectively, as can be seen in Fig 5. In most cases, increases in R2 values were observed with increase in mixing ratio.

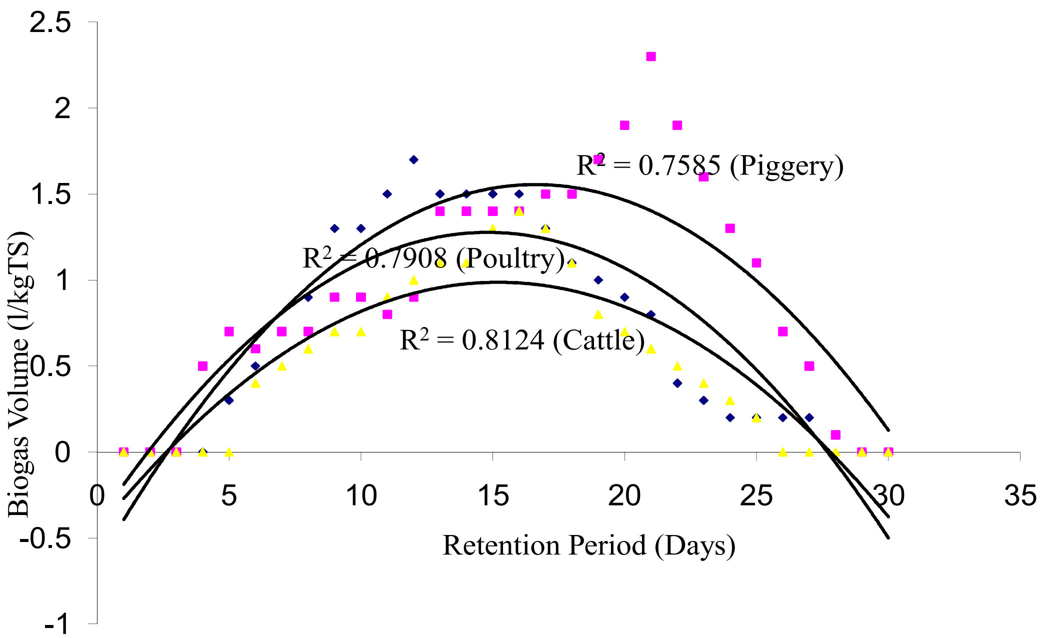

Figure 4: Rate of biogas production for mixing ratio 1:1 for piggery, cattle and poultry wastes

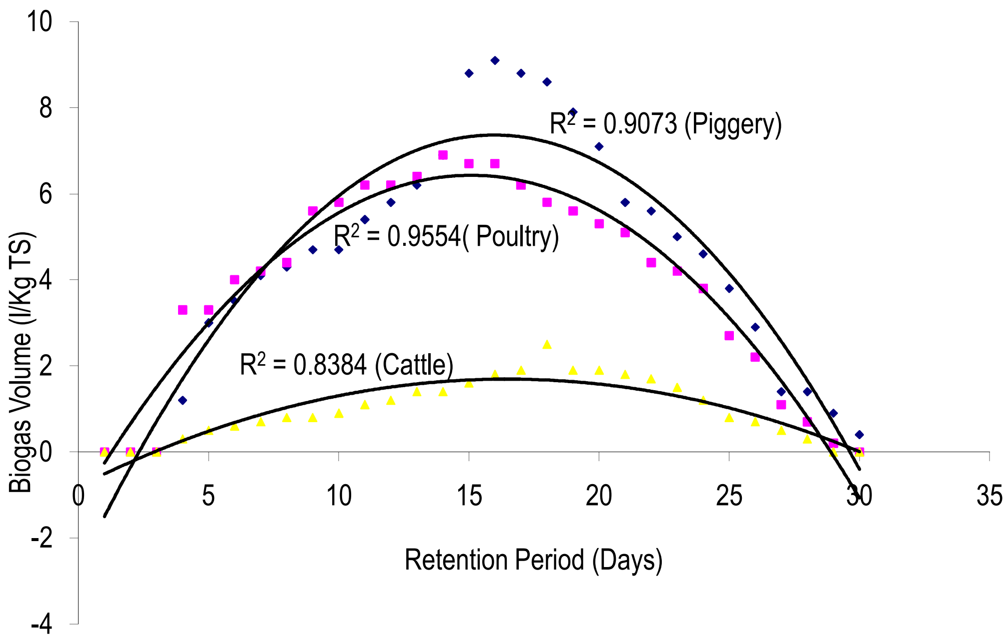

Figure 5: Rate of biogas production for mixing ratio 3:1 for piggery, poultry and cattle wastes

CONCLUSIONS AND RECOMMENDATIONS

This experiment shows the tremendous potential for the generation of biogas which is available from livestock wastes. Specifically, the following are noticeable from the experiment. For poultry and piggery wastes, slurries mixed in ratios 3:1 waste:water produced more biogas than those of 2:1 and 1:1 ratios. In the case of cattle waste, the 2:1 mixing ratio produced the most biogas. Slurries containing piggery waste produced more biogas than corresponding mixing ratios of other livestock waste types. The exception is the 3:1 ratio, which showed poultry waste producing the highest biogas volume. Cattle waste produced the least biogas volumes for all mixing ratios. This work recommends a livestock wastes: water mixing ratio of 3:1 for poultry and piggery slurries, and 2:1 for cattle slurry intended for biogas production from methane-generating systems, given 30% TS content.

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