

Effect of retention time on gas production and fertilizer value of biodigester effluent

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Abstract

Two experiments were carried out to study gas production and fertilizer value of the effluent in plug-flow, tubular, plastic biodigesters with hydraulic retention times of 10, 20 or 30 days (BRT10, BRT20 or BRT30). There were three biodigesters each of 510 litres liquid volume in each experiment which consisted of three consecutive periods (retention times) of 40 days arranged in a 3*3 Latin Square. In experiment 1, the quantity of fresh pig manure was 5.1 kg/day, mixed with 46, 20 or 12 litres of water to give retention times of 10, 20 or 30 days, respectively. In experiment 2, the proportions of pig manure and water were maintained constant to give a total solids content of 60 g/litre in the influent, which was added at rates of 51, 25.5 and 17 kg daily for retention times of 10, 20 or 30 days, respectively. Gas production was measured daily by water displacement in inverted lightweight containers (tubular polyethylene supported by bamboo strips) suspended in 200 litre drums filled with water. Influent and effluent were analyzed at weekly intervals for DM, OM, pH and total nitrogen and ammonia-nitrogen. Gas production was measured daily but only the data for the last 10 days of each period were used in the statistical analysis.

With a fixed daily input of fresh manure, neither the rate of gas production (1.04, 1.20 and 1.12 volumes of biogas per unit liquid volume of the biodigester) nor the efficiency (493, 606 and 567 litres of biogas/kg of manure organic matter added to the biodigester), was influenced by retention time (10, 20 or 30 days, respectively). However, when the solids concentration of the influent was fixed at 60 g/kg, rates of gas production were reduced by increasing retention times (1.62, 1.19 and 0.81 volumes biogas/unit liquid volume of biodigester for 10, 20 and 30 days retention); efficiency was better for 20 and 30 days retention (550 and 547 litres biogas/kg OM) than for 10 days (376 litres/kg OM). The proportion of ammonia-N in total-N increased from a range of 0.077 to 0.12 in the fresh manure to a range of 0.46 to 0.65 in the effluent and did not appear to be affected by retention time or loading rate.

It is concluded that when fresh pig manure is the substrate in polyethylene plug-flow biodigesters the optimum retention time is between 10 and 20 days with a solids concentration in the influent of 60 g/litre. The retention time apparently has no effect on the degree of conversion of organic N to ammonia-N.

Key words: *Biodigester, effluent, fertilizer value, gas production, pig manure, polyethylene, retention time*

Introduction

The high population density is putting pressure on the use of natural resources causing damage to the world environment (Bui Xuan An and Preston 1998; Ding Jieyi and Han Yujin 1984). A particularly serious problem is the pollution caused by large commercial farms and factories (Preston and Leng 1989). The increased agricultural productivity has also had big effects on the soil fertility depletion. One of the ways to solve the problem is the promotion of integrated farming systems, with minimal external inputs and recycling of all wastes. The most important feature of this approach is the recycling of animal wastes in order to prevent deterioration of soil fertility through loss of nutrients and organic matter, erosion and salinity (Preston and Rodriguez 1996). For instance applying the manure to the soil can reduce environmental pollution and also improve the fertility of the soil through recycling of plant nutrients to the soil.

Biodigesters play a crucial role in the conversion of organic matter to methane-rich biogas, with positive impacts on the environment and on human and animal health. and Soeurn Than (1994) have demonstrated that plastic tube biodigesters can be a low-cost source of energy and partly reduce the problem of severe energy shortage for households in rural areas of Vietnam and Cambodia. However, it has been argued that few farmers used biogas in practice (Kristoferson and Bokalders 1991), although its use is increasing rapidly in some developing countries under extensive support from governments and agencies (Marchaim 1992; Karki 1996). Besides environmental preservation, biodigesters provide a very good source of fertilizer for crops on land and water, and for fishponds (Preston and Rodriguez 1996). Biogas used for cooking reduces the need for firewood and also the time and labor for finding other fuels. It also saves the costs of buying wood (NRC 1981).

The integration of livestock with trees, food crops and aquaculture is seen as the most appropriate way to use the natural resources in a system that is productive and sustainable in the long term (Preston 2000). Biodigester effluent can be applied to crops (rice field, cassava, and other perennial crops), vegetables (salad, tomatoes cabbage and water spinach) and in ponds (fish or water plants). In this connection, Rodriguez and Preston (1997) and Leng (1999) reported that yields of duckweed responded linearly to increasing levels of nitrogen in the effluent from pig manure. Similar responses were observed by Sophea and Preston (2001) from applying biodigester effluent to water spinach. Biodigester effluent is potentially superior to raw manure fertilizer because the anaerobic digestion process results in conversion of organic nitrogen in the manure to ionized ammonia (NH_4^+), which can be used directly by plant roots (Forchhammer 1994).

According to previous research (Boodoo et al 1979; Bui Xuan An and Preston 1999), there are many factors that influence gas production and the fertilizer value of the effluent, such as retention time, temperature, types of manure and concentration of solids in the influent. In the current study, it is proposed to evaluate the effect of hydraulic retention time of diluted pig manure in plug-flow polyethylene biodigesters on rate of gas production and the fertilizer value of the effluent.

Objectives

- This was to determine the gas production rate and the total nitrogen, ammonia nitrogen, pH, and chemical oxygen demand in the effluent from biodigesters with different retention times

Hypothesis

- It is hypothesized that increasing the retention time will increase the proportion of organic nitrogen converted to ammonia-N in the effluent

Materials and methods

Location

The experiments were conducted in the experimental farm of the University of Tropical Agriculture Foundation (UTA) located on the campus of the Royal University of Agriculture (RUA), Chamcar Daung, Dangkor district, Cambodia, about 10 km from Phnom Penh City.

Experimental plan

Two experiments were carried out:

- The first experiment “**Effect of retention time in biodigesters charged daily with a constant daily amount of pig manure**” began on May 10, 2002 and finished on October 9, 2002;
- The second “**Effect of retention time in biodigesters charged with a constant manure concentration in the influent**” began on June 14, 2002 and finished October 16, 2002.

Experimental treatments and design

In both experiments, the design of biodigester, the experimental design and the treatments were the same. The treatments were:

- BRT10 retention time 10 days
- BRT20 retention time 20 days
- BRT30 retention time 30 days

The experimental design was a 3*3 Latin square arrangement of the three retention times with 3 periods each of 40 days, applied to 3 biodigesters (Table 1). The first 30 days of each period were of adaptation to the new retention time followed by 10 days of measurements.

Table 1: Arrangement of treatments

Biodigester/Days	I	II	III
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0-40	BRT30	BRT20	BRT10
41-80	BRT10	BRT30	BRT20
81-120	BRT20	BRT10	BRT30

Manure

Pig manure was collected daily in the early morning from the pig pen of Mong Cai animals. The pigs were being fed a mixed feed formulated from wheat bran, broken rice, fishmeal, salt and premix as detailed in Table 2.

Table 2: Composition of the pig feed

	Air dry basis (%)
Wheat bran	45
Broken rice	45
Dry fish	9.45
Salt	0.5
Premix	0.05

DM content 87%, protein in DM 12.6%

Biodigesters

The six plug-flow biodigesters (in each experiment there were three biodigesters) were made from tubular polyethylene film (internal diameter 0.64m) and mounted in shallow trenches lined with bricks to ensure the dimensions were exactly the same (2 m length, 0.6 m depth and 0.6m width), to provide a liquid volume in the proportion of 80% of the total biodigester capacity. This was calculated to be 510 litres (Photo 1). The biodigesters were installed in an area with the same microclimate condition by shading them with plastic net 3 m above the ground. At the beginning of each experimental period, the biodigesters were inoculated with 140 litres of effluent from another biodigester, followed by a mixture of 5 kg fresh pig manure and 45 litres water applied each day for 10 days. During the subsequent adaptation and data collection periods, the fresh pig manure and water were added in the proportions indicated for each loading rate treatment.



Photo 1: The construction details of each unit of three biodigesters

The quantity and characteristics of the materials that were used in the construction of the biodigesters and the installation process are set out in Appendix 1.

Manure input

The biodigesters were charged daily at exactly the same time and with the amounts of fresh manure and water according to the treatments and the liquid volume of the biodigester (Tables 3 and 4).

Experiment 1

The amount of fresh pig manure was fixed at 5.1 kg (1.18 kg DM) per day with addition of different amounts of water (Table 3) in order to give the different retention times. This resulted in concentrations of dry matter in the input material of 2.3, 4.6 and 6.9 % (weight / volume basis).

Table 3: Details of the biodigesters and loading rates for the first experiment

	Dimensions	BRT10	BRT20	BRT30
Manure DM, %				
Range	18.9-28.9			
Mean value	23.2±1.31			
Biodigester details				
Length, m	2			

Diameter, m	0.64			
Volume of biodigester, m ³	0.64			
Liquid volume, litres	510			
Liquid applied daily, litres		51	25.5	17
Manure, kg/d		5.1	5.1	5.1
Manure DM, kg			1.17	
Water, litres/d		45.9	20.4	11.9
Solids (DM) concentration, %		2.3	4.6	6.9

Experiment 2

The concentration of manure in the influent was maintained constant at 6.0% solids (DM). This required the addition daily of 10.7, 5.4 and 3.6 kg fresh manure, and 40.5, 20.2 and 13.5 litres of water (Table 4).

Table 4: Details of the biodigesters and loading rates for the second experiment

	Dimensions	BRT10	BRT20	BRT30
Manure DM, %				
Range	27.2-30.62			
Mean value	28.7±2.03			
Biodigester details				
Length, m	2			
diameter, m	0.64			
Biodigester volume, m ³	0.64			
Liquid volume, litres	510			
Liquid, litres/d		51.2	25.6	17.1
Manure, kg/d		10.7	5.4	3.6
Manure DM, kg		3.1	1.5	1.0
Water, litres/d		40.5	20.2	13.5
Solid concentration, %			6.00	

Data collection and analyses

The experimental data were recorded daily during the last 10 days of each experimental period. Samples of fresh pig manure and the corresponding effluent were taken daily on days 31 to 40, immediately before (manure) and after (effluent) charging the biodigester. They were stored in a refrigerator at -12°C. Gas production was measured daily throughout the experiment but only the data for the last 10 days were used in the statistical analysis.

The samples of fresh manure were bulked and mixed every 5 days, and of effluent every 3 days, prior to taking representative samples for analysis of nitrogen and ammonia using a Foss-Tecator Kjeldahl apparatus and for organic matter by ashing the samples in a furnace oven (AOAC 1990). DM content was determined by microwave radiation (Undersander et al 1993). Chemical oxygen demand (COD) was measured in representative samples of effluent taken two times during each collection period, and analysed immediately (Andrew et al 1996). The pH of the manure and effluent was measured daily

using a glass electrode and digital meter. VFA was determined by steam distillation in three samples of effluent taken at 3 day intervals during each measurement period.

Gas production was measured daily by collecting the gas in inverted light-weight containers (a plastic-covered bamboo frame) of 200 litres capacity, floating inside oil drum containers filled with water, and permanently connected to the gas outlet of each biodigester (Photo 2). The change in volume was recorded four times a day to determine daily gas production.



Photo 2: The inverted containers for collecting the biogas by water displacement

Statistical analyses

The data were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) of the MINITAB software Release 13.31 (2000). The model was:

$$Y_{ij k} = \mu + T_i + P_j + A_k + e_{ijk}$$

Where:

$Y_{ij k}$: Dependent variable

μ : Overall mean

T_i : Treatment effect

P_j : Period effect

A_k : Biodigester effect

e_{ijk} : Random error

Results

Experiment 1: Effect of retention time on gas production and fertilizer values with input of constant quantity of manure

Manure and slurry input

There were differences in the DM content of the manure and the pH, and in the total N concentration during the successive periods of experiment 1 (Table 5). Ammonia-N as a proportion of total N was in the range of 0.023 to 0.029 and did not vary between periods. Ammonia-N as proportion of total N was a little higher in the input slurry (0.04 to 0.08 mg/litre) presumably reflecting microbial action between the time taken to sample the raw manure and add water to make the influent slurry.

The differences in DM and N content, among retention times, reflect the effect of the addition of water. There were no differences due to retention time in pH, OM, VFA, nitrogen, NH₃-N and the proportion of NH₃-N in total N.

Table 5: Manure and slurry input characteristics

Manure	Period			SEM	Prob.
	1	2	3		
DM, %	28.9	21.9	18.9	1.31	0.046
OM, % in DM	85.7	84.1	85.6	1.35	0.769
pH	6.98	6.74	5.74	0.22	0.001
VFA, m-equiv/100mg	48.4	76.0	68.1	8.59	0.303
Slurry	Retention times				
	10	20	30		
pH	6.64	6.61	6.71		
DM, %	1.86	3.58	7.28		
OM, % in DM	88.17	87.15	90.38		

Biogas production

At the beginning, the biodigesters were inoculated with 140 litres of effluent from another biodigester, followed by 5 kg of fresh pig manure and 36 litres of water per day for 10 days.

Gas production began on the 7th day from the start of the inoculation period (Figure 1 and gradually increased during the adaptation period before reaching a plateau on or about day 25 of the adaptation phase in period 1 (Figure 2). Subsequently gas production rates were similar on all three retention times (Figures 2, 3 and 4).

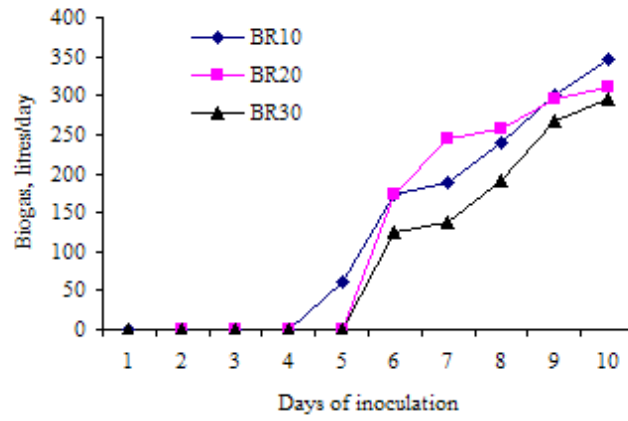


Figure 1: Initiation of gas production during the ten day period of inoculation

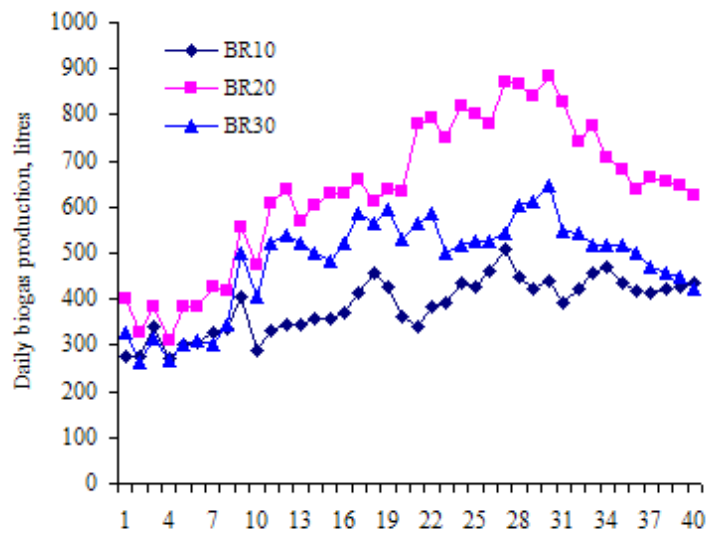


Figure 2: Biogas generation during period 1.

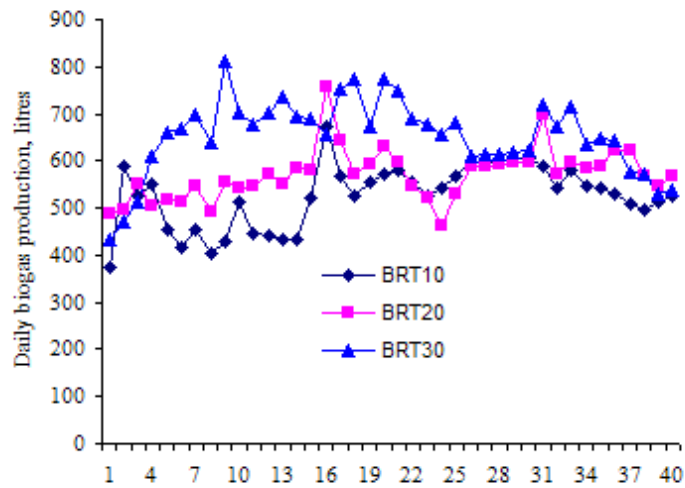


Figure 3: Biogas production during the second period

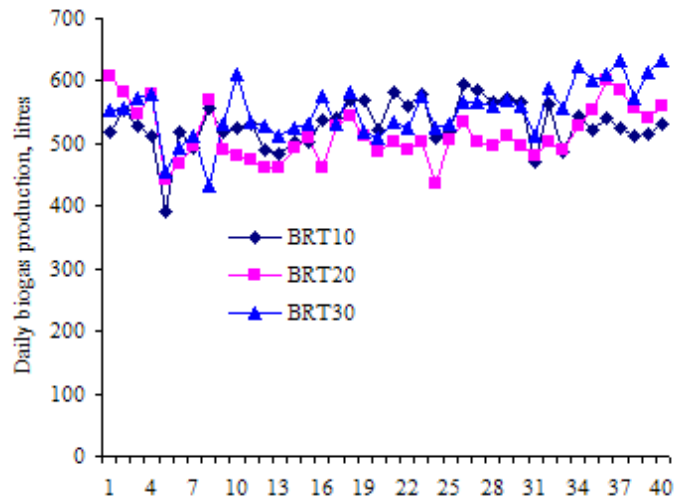


Figure 4: Biogas production during the third period

Mean values for rates and efficiency (litres gas per input of DM and OM or per liquid biodigester volume) of gas production during the 10 days of data collection (Table 6; Figures 5, 6, 7) were not influenced by retention time, period or biodigester. The rate and efficiency of gas production tended to be lower for 10 day retention time with no differences between 20 and 30 days (Figure 7). There were no differences in any of the measurements between biodigesters. The air temperature varied from 26 to 31 °C during the experiment and did not differ among periods.

Table 6: Effect of retention time, period and biodigester, on gas production with constant manure (5.1kg) addition giving different concentrations of DM (2.3, 4.6 and 6.9%) in the influent for retention times of 10, 20 and 30 days.

Retention times	10	20	30	SEM	Prob.
<i>Biogas production litres per</i>					
Day	496	611	571	43.4	0.358
Per unit liquid biodigester volume	0.97	1.20	1.12	0.08	0.352
kg DM in influent	441	527	508	31.3	0.324
kg OM in influent	519	619	598	36.2	0.318
Periods	1	2	3		
<i>Biogas production litres per</i>					
Day	540	586	552	43.4	0.768
Per unit liquid biodigester volume	1.06	1.15	1.08	0.08	0.449
kg DM in influent	370	526	581	31.3	0.075
kg OM in influent	431	627	679	36.2	0.071
Biodigester	I	II	III		
<i>Biogas production, litres per</i>					
Day	524	614	540	43.4	0.449
Per unit liquid biodigester volume	1.03	1.20	1.06	0.08	0.460
kg DM of influent	464	529	485	31.3	0.472
kg OM of influent	545	622	570	36.2	0.460
Periods	1	2	3		
Air temperature, °C	26.0	31.0	30.3	2.8	0.444

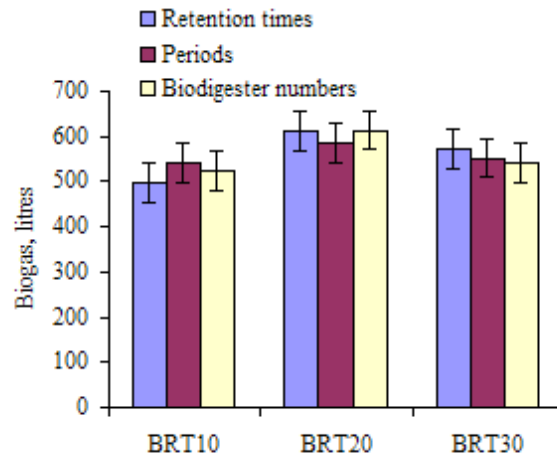


Figure 5: The effect of retention time, period and biodigester on daily gas production (Experiment 1)

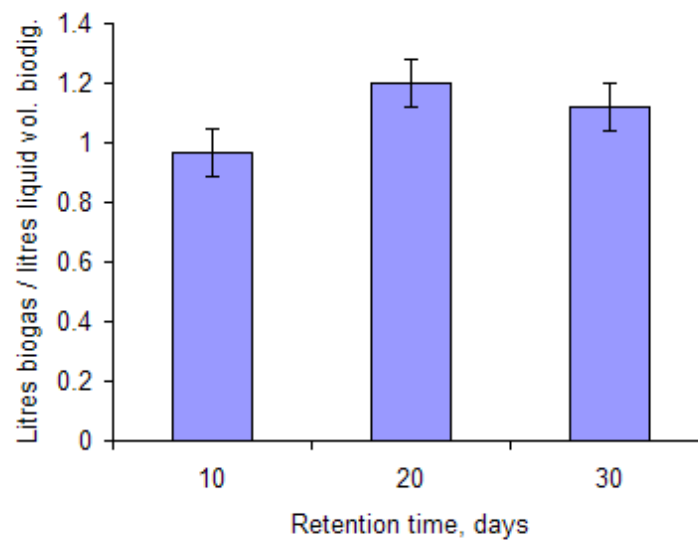


Figure 6: Biogas production per liquid biodigester volume with manure quantity constant

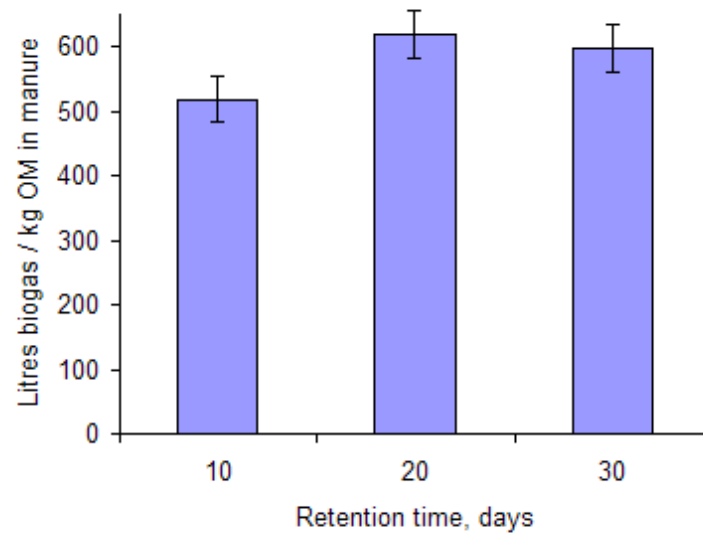


Figure 7: Biogas production per kg manure OM with constant amount of manure daily

Effluent characteristics

The DM, total N and ammonia-N concentrations in the effluent increased with retention time reflecting the DM concentrations in the influent. pH and ammonia-N as proportion of total N increased with retention time as did the COD values (Table 7 and Figure 8).

Table 7 : Effect of retention time on fertilizer value with constant manure (5.1kg) or different manure concentration input (2.3, 4.6 and 6.9%)

<i>Effluent</i>	Retention times, days			SEM	Prob.
	10	20	30		
pH	6.77	6.94	7.14	0.09	0.082
DM, %	1.55	3.06	4.60	0.85	0.001
OM, %	66.2	70.9	75.2	6.03	0.207
Total N, mg/litre	889	1476	1690	181.7	0.049
NH ₃ -N, mg /litre	340	633	884	64.7	0.003
NH ₃ -N in total N	0.40	0.45	0.53	0.02	0.017
VFA, m-equiv/100g	18.3	20.5	20.9	5.94	0.84
COD _{Cr} , mg/litre	2.04	4.37	17.08	2.87	0.025

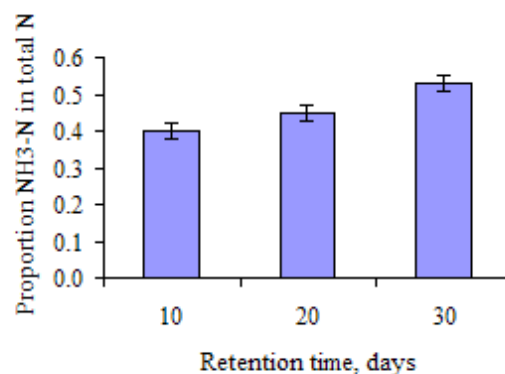


Figure 8: Effect of retention time on proportion of ammonia-N to total N in effluent

from biodigester with constant daily manure input

Experiment 2: Effect of retention time on gas production and fertilizer values with constant manure concentration

Manure and slurry input

There were no differences in the characteristics of the manure, nor in the input slurry, among the three periods in Experiment 2 (Table 8). Ammonia-N as a proportion of total N increased when the manure was diluted with water prior to charging the biodigester and reached values of between 0.5 and 0.6 in the effluent (Figure 9).

Table 8: Manure and slurry input characteristics

Manure characteristics	Period			SEM	Prob
	1	2	3		
pH	6.33	6.21	6.86	0.091	0.048
DM, %	30.6	27.2	28.4	2.03	0.656
OM, %	78.0	73.7	84.3	2.97	0.263
VFA, m-equiv/100g	88.9	73.6	62.4	5.104	0.124
Slurry input	Treatments			SEM	Prob
	BRT10	BRT20	BRT30		
pH	6.93	6.73	6.89	0.131	0.696
DM, %	2.70	2.77	2.82	0.182	0.936
OM, % in DM	81.5	81.0	80.9	3.940	0.996
VFA, m-equiv/100g	5.00	5.37	2.14	2.352	0.715

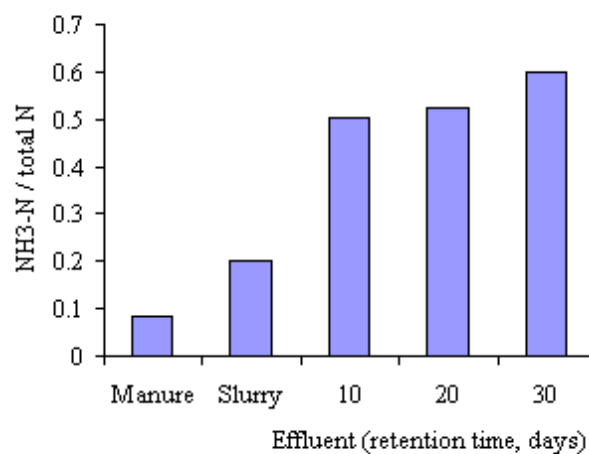


Figure 9: NH₃-N as proportion of total-N in manure and slurry (diluted manure before charging the biodigester)

Biogas production

The initiation of gas production was observed after some 7 days during the period of inoculation (Figure 10).

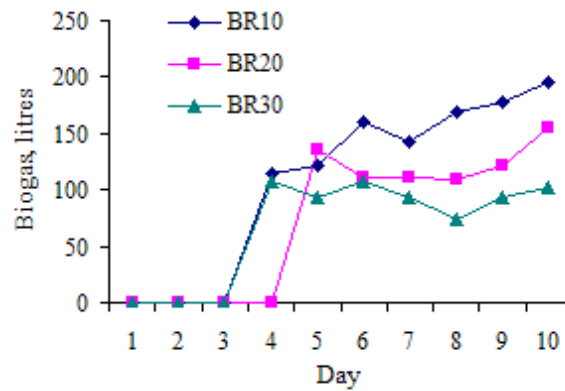


Figure 10: Gas production during the inoculation period in Experiment 2

Production rate then increased steadily until reaching a plateau after 20 to 25 days in the adaptation period, with production rates almost always higher for the 10 day retention treatment than the 20 and 30 day retention times (Figures 11, 12 and 13).

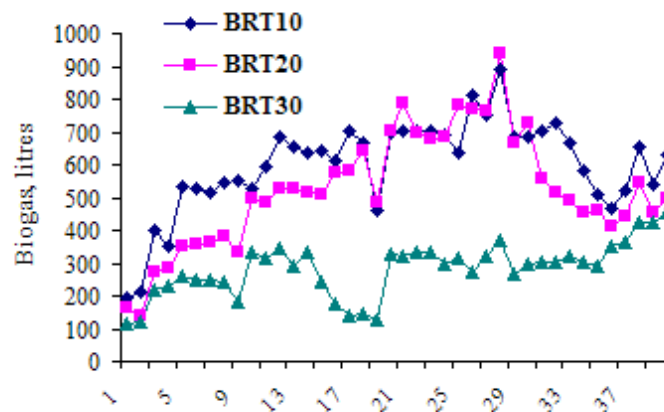


Figure 11 : Gas production in the adaptation phase of the first period with constant manure concentration

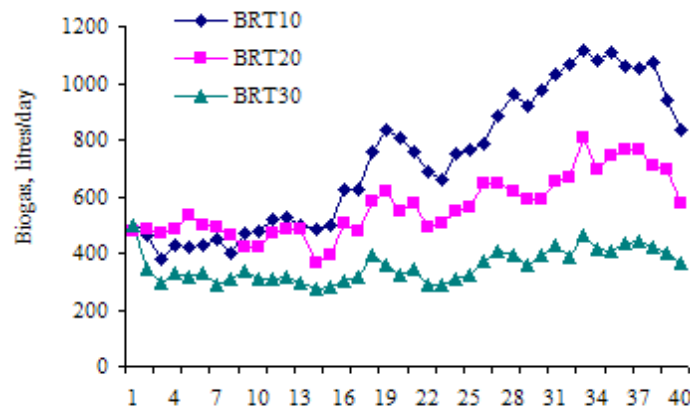


Figure 12: Gas production in the adaptation phase of the second period with constant manure concentration

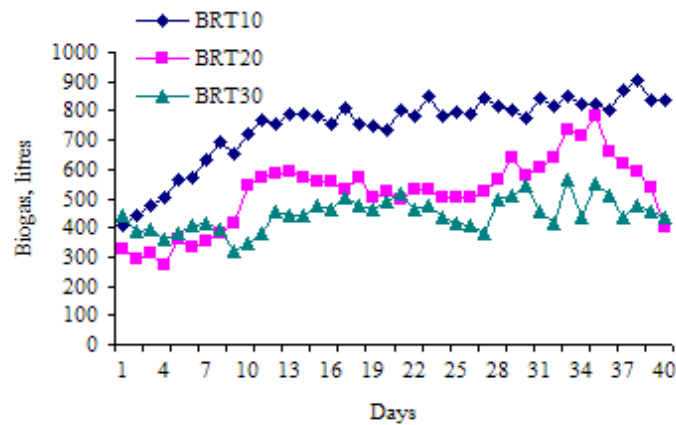


Figure 13: Gas production in the adaptation phase of the third period with constant manure concentration

Mean values for gas production rate during the 10 day collection period were highest for the 10 day retention treatment and lowest for 30 days (Table 9; Figures 14, 15). By contrast, efficiency of gas production was lowest for 10 day retention time with no differences between 20 and 30 days (Figure 16). Gas production tended to be higher during the second and third period and efficiency 40 to 50% greater during these periods compared with period 1. The ambient temperature was 2 to 3 °C higher in periods 2 and 3 compared with period 1. There were no differences in any of the measurements between biodigesters.

Table 9: Effect of retention time, periods and biodigester numbers on gas production with constant manure concentration (6%) from the mean of periodic analysis

<i>Retention time</i>	<i>BRT10</i>	<i>BRT20</i>	<i>BRT30</i>	<i>SEM</i>	<i>Prob</i>
Biogas production litres per					
Day	819	606	414	59.1	0.078
Per unit liquid biodigester volume	1.61	1.19	0.81	0.1	0.079
kg DM	289	431	431	15.8	0.036
kg OM	468	516	498	22.6	0.054
Periods					
	<i>I</i>	<i>2</i>	<i>3</i>		
Day	479	720	640	59.1	0.188
Per unit liquid biodigester volume	0.94	1.42	1.26	0.1	0.189
kg DM	286	451	414	15.8	0.032
kg OM	366	611	505	22.6	0.033
Biodigester					
	<i>I</i>	<i>II</i>	<i>II</i>		
Day	573	594	672	59.1	0.558
Per unit liquid biodigester volume	1.13	1.17	1.32	0.1	0.568
kg DM	352	405	394	15.8	0.242
kg OM	385	550	547	22.6	0.467
Periods					
	<u>1</u>	<u>2</u>	<u>3</u>		
Air temperature, °C	27.0	30.3	29.3	2.41	0.636

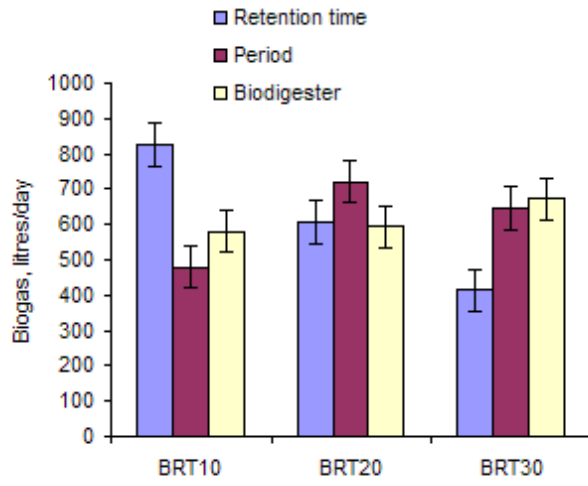


Figure 14: Effect of retention time, period and biodigester, on rate of gas production, with constant concentration of solids in influent (Experiment 2)

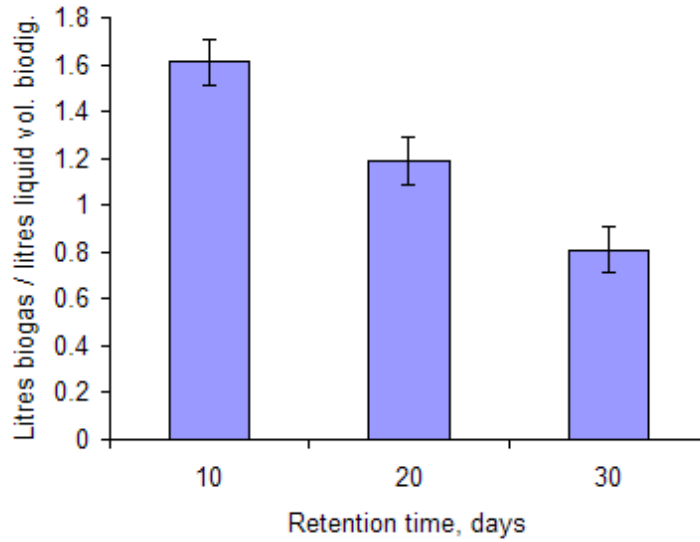


Figure 15: Biogas production per liquid biodigester volume with constant DM concentration in the influent

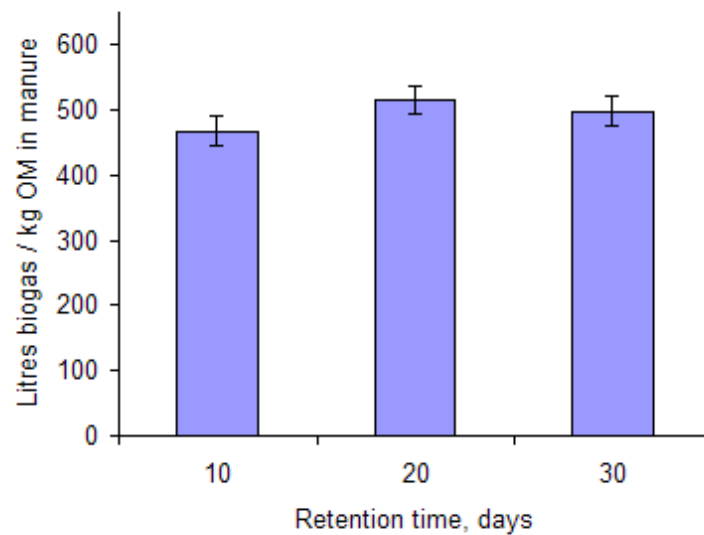


Figure 16: Biogas production per kg manure OM with constant DM concentration in influent

Effluent characteristics

There was no effect of retention time on the characteristics of the effluent (Table 10). Ammonia-N as proportion of total N tended ($P=0.17$) to increase with retention time. COD values were low and not affected by retention time.

Table 10: Effect of retention time on effluent characteristics with constant manure concentration input (60 g DM/litre) by mean value of each period (Experiment 2)

	Treatments			SEM	Prob
	BRT10	BRT20	BRT30		
pH	6.95	7.08	7.05	0.09	0.561
DM, %	1.95	2.89	2.21	0.53	0.484
OM, % in DM	73.5	72.7	71.5	2.05	0.783
N, mg/litre	995	1158	1099	181	0.818
NH ₃ -N, mg/litre	486	573	647	66.8	0.308
NH ₃ -N in total N	0.50	0.53	0.60	0.03	0.171
VFA, m-equiv/100g	14.0	12.3	11.0	0.98	0.135
COD, mg/litre	3.52	2.28	3.00	0.65	0.455

Discussion

Gas production

The two experiments used contrasting methods of varying the hydraulic retention rate: in Experiment 1 the daily input of manure was held constant while in Experiment 2 the concentration of manure in the influent was held constant. Thus loading rate, expressed as kg manure DM/m³ of digester liquid volume, was constant in Experiment 1 (2.29) for all

retention times while in Experiment 2, the loading rates were 6.1, 3.0 and 1.96 for retention times of 10, 20 and 30 days, respectively. It was apparent from the results that retention time was poorly related with gas production and that the determining factor was the loading rate as illustrated by the regression of gas production on loading rate ($R^2 = 0.90$) using data from both experiments (Figure 17). This conclusion is supported by the data in the literature (Table 11; Figure 18), which in spite of the wide range in locations showed a relatively strong relationship ($R^2 = 0.68$) between rate of gas production (m^3 gas/ m^3 digester liquid volume) and the loading rate.

Table 11: Literature reports for rates and efficiency of gas production in biodigesters

#Loading rate kg DM/ m^3	Air temp, °C	##Gas per unit liquid volume	Gas, litres/kg DM	Retention time, days	Country	Reference
### nd		0.10 – 0.27	417-921	30	Vietnam	Lotte et al 96
nd	35	0.86		7.2	Canada	Li Sui Fong et al 84
0.53	29-33	2.49		70	Thailand	Polprasert et al 85
0.61		0.46		18-47	nd	Hamilton et al 84
0.66		0.19	299	30	Vietnam	Bui Xuan An and Preston 99
0.7		.242	121	64	Vietnam	Bui Xuan An et al 95
.75		.19		50	Thailand	
.85	30	.24	282	40	Mauritius	Boodoo et al 79
1.0		0.42	426	40	Vietnam	Khang et al 02
1.2		0.33	280	30	Thailand	Polprasert et al 82a
1.2	29-33	.28		30	Thailand	Polprasert et al 85
1.33		0.47	363	30	Vietnam	Bui Xuan An and Preston 99
1.66	35	0.83	390	22	USA	Safley et al 87
1.8	30	.26	144	20	Mauritius	Boodoo et al 79
1.96		.81	414	30	Cambodia	Expt 2
2		0.73	374	30	Vietnam	Bui Xuan An and Preston 99
2.29		1.17	560	10-30	Cambodia	Expt 1
2.3	30.3	1.2		30	Thailand	Patelunnas and Regan 77
2.66		0.93	359	30	Vietnam	Bui Xuan An and Preston 99
2.7	35	1.13	310	30	UK	Hayes et al 79
3.0		1.19	451	20	Cambodia	Expt 2
3.05	30	.26	85	10	Mauritius	Boodoo et al 79
4	35	2.3	1340	15	USA	Fischer et al 79
6.1		1.61	286	10	Cambodia	Expt 2

#Loading rate is kg DM added daily to the digester per m^3 of biodigester liquid volume; ## Gas production in m^3/ m^3 of the liquid volume of the biodigester; ### no data

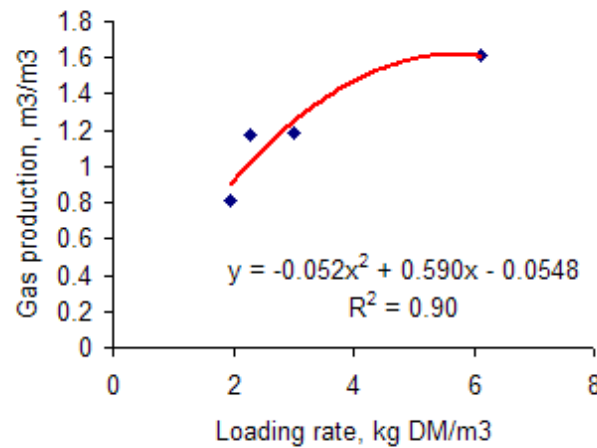


Figure 17: Relationship between loading rate and gas production (experiments 1 and 2)

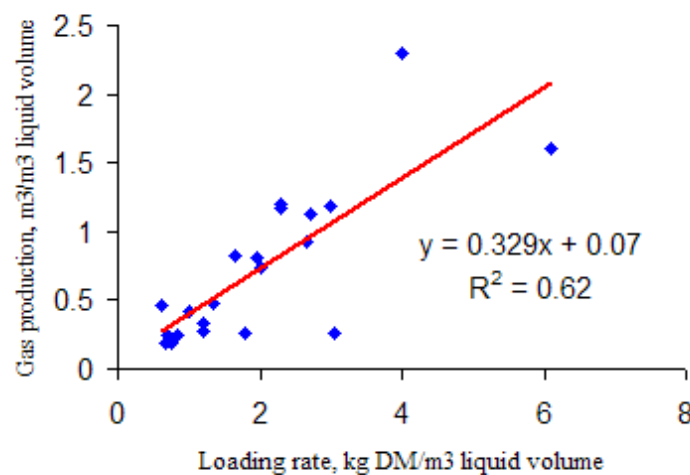


Figure 18: Relationship between loading rate and gas production (data from Table 11)

Effluent fertilizer value

In both experiments the increase in retention time resulted in slight increases in the proportion of ammonia-N in total N (from 0.40 to 0.53 in Experiment 1 and from 0.50 to 0.60 in Experiment 2, for 10 and 30 day retention times, respectively). In both experiments the proportion of ammonia-N in total N was low in the raw manure (range 0.02 to 0.04) and increased markedly in the effluent (range of 0.40 to 0.60). These data support the original hypothesis that longer retention times would support a greater degree of conversion of organic-N in the influent to ammonia-N in the effluent. The effect of the retention time on this parameter is discussed in subsequent experiments to verify this (Santhy et al 2003). The substantial improvement in ammonia-N as proportion of total N in effluent as opposed to the influent (from 0.02 to 0.50) is in accordance with the findings of Pedroza et al (2001) who reported increases from 0.2 in the influent to 0.60 in the effluent.

Chemical oxygen demand

The COD values in effluent registered in both experiments were at the low end of values reported in the literature (Table 12). Only in experiment 1 was there a relationship with retention time, with higher values for the longer retention times. However, as retention time was confounded with concentration of DM in the effluent, the higher COD values for the longest retention time could have been due to the higher solids concentration creating less favourable circumstances for breakdown of organic matter. The negative effect of the longer retention is the opposite of the findings reported by Polprasert et al (1985) where COD was lower with longer retention times (24.8, 17.7 and 14.9 mg/litre for retention times of 30, 50 and 70 days. Khang et al (2002) reported that COD increased from 48 to 675 mg/ litre as the manure concentration was increased from 1 to 4% DM in the influent). The trend for effects of retention time were similar to our findings, although of a higher order of magnitude, as COD increased from 114 to 690 mg/litre with retention times increasing from 10 to 40 days.

Conclusions

With a fixed daily input of fresh manure, neither the rate of gas production (0.97, 1.2 and 1.12 volumes of biogas per unit liquid volume of the biodigester) nor the efficiency (546, 619 and 598 litres of biogas/kg of manure organic matter added to the biodigester), were influenced by retention time under study (10, 20 or 30 days, respectively). However, when the solids content of the influent was fixed at 60 g/kg, rates of gas production were reduced by increasing retention times (1.62, 1.19 and 0.81 volumes biogas/unit liquid volume of biodigester for 10, 20 and 30 days retention), while efficiency was better for 20 and 30 days retention (550 and 547 litres biogas/kg OM) than for 10 days (376 litres/ kg OM).

With a fixed concentration of manure DM in the influent, the proportion of ammonia-N in total-N increased from a range of 0.077 to 0.12 in the fresh manure to a range of 0.50 to 0.60 in the effluent and did not appear to be affected by retention time.

Analysis of the data from the two experiments and from reports in the literature showed that the major determinant of rate of gas production was the loading rate expressed as kg of manure solids per m³ of liquid digester volume.

It is concluded that when fresh pig manure is used as substrate in polyethylene plug-flow biodigesters the optimum retention time is between 10 and 20 days with a solids concentration in the influent of 60 g/litre.

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