Asian Journal of Biotechnology and Bioresource Technology

1(2): 1-10, 2017; Article no.AJB2T.35661

Anaerobic Digestion of Abattoir Waste: A Combined Strategy for Biogas and Biofertilizer Production, and Waste Management

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Authors' contributions

The study presented herein is a collaborative study carried out by all the aforementioned authors. Authors MIA and OAO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author FBW managed the analyses of the study while author DM conducted and interpreted the microbial analysis. All authors were involved in the literature searches for the study. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJB2T/2017/35661
Editor(s):
(1) Jayanta Kumar Patra, Research Institute of Biotechnology & Medical Converged Science, Dongguk University, Ilsandong, Republic of Korea.
Reviewers:
(1) E. U. Eleanya, Veritas University, Nigeria.
(2) Anna Aladjadjiyan, Retired from the Agricultural University-Plovdiv, Bulgaria.
Complete Peer review History: http://prh.sdiarticle3.com/review-history/20448

Original Research Article

Received 24th July 2017
Accepted 4th August 2017
Published 9th August 2017

ABSTRACT

Aims: The study was carried out to estimate the biogas and biofertilizer potential of cattle Paunch and assess the waste treatment efficiency of the Anaerobic Digestion process.
Place and Duration of Study: The study was carried out at the Department of Water Resources and Environmental Engineering, Ahmadu Bello University Zaria between March and August 2016.
Methodology: We digested paunch from the rumen of one cow anaerobically for 30 days. Biogas production was measured. The digestate compost was used in comparison with Urea to cultivate maize. The plant heights, Plant diameter, average growth rate, number of cobs and weight of cobs were the performance indicators. The results obtained for each parameter were subjected to a Two Way ANOVA at 95% Confidence level using Minitab 14.2 Statistical software. Physicochemical and microbial characteristics of the feedstock and digestate were used as indicators of the treatment efficiency.

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Results: 0.61 m^3 of biogas was produced over the retention time while the potential biogas production of one mature cow was estimated at 7.43 m^3/year. A total of 14.7 kg of digestate compost was obtained and utilized for the maize production. The results of the ANOVA showed that there was significant difference between the treatments for all parameters with a *P*-value of .000 in each case. Only plant height showed significant different between plots with a *P-value* of .035. 53.13% percent reduction in Total solids was achieved by the anaerobic digestion process while the reduction in Volatile solids, Chemical Oxygen Demand, *E. coli* and *Enterobacteriaceae* were 47.12%, 29.10% 86.75% and 91.28% respectively while the overall efficiency was estimated at 63.86%.

Conclusion: Biogas in good quantity and compost was produced via the anaerobic digestion of cattle paunch and the process achieved over 60% waste treatment efficiency.

Keywords: Abattoir waste; biogas; biofertilizer; digestate; waste management; maize yield.

1. INTRODUCTION

Abattoir wastes is one of the major challenges confronting the management of municipal waste as they can pollute surface and ground waters, abattoir/market area etc especially when there is no proper treatment and disposal [1]. The nature of abattoir waste makes it a potential energy source if properly harnessed using the appropriate technology. The importance of this in a developing economy like Nigeria cannot be overemphasized. This becomes increasingly necessary at such a time when serious pressure is mounted on the limited energy supply in Nigeria. More so, the utilization of fuels of fossil origin has been reported to have adverse impact on the climate and could also impact negatively on human health [2].

Anaerobic digestion of the organic component of abattoir waste (especially rumen content) could produce a clean fuel called biogas and digestate which could be a rich source of nutrients for plants growth [3-5].

Studies have shown that the application of chemical fertilizers for augmenting the supply of essential nutrients for plant growth can pollute the ground water resources, destroy microorganisms, increase the susceptibility of crops to disease attack, amongst others [6]. Besides, Urea ($CO(NH_2)_2$) which is the most commonly used Nitrogen (N) chemical fertilizer has the tendency of losing a large percentage of its Nitrogen in the form of Ammonia (NH_3) which increases greatly at temperatures above 15.6°C [7]. The mean soil temperature for the southern part of Nigeria is 28.7°C [8] and it is expected to increase with increasing distance from the coast towards the high temperature northern part with very few exceptions [9]. More so, studies have shown that the presence of impurities such as biuret and cyanate could have adverse effect on seed germinations [10]. Organic fertilizers on the other hand although has lower nutrient content and releases these nutrients at relatively slower rates, are able to overcome nearly all the disadvantages of the chemical ones [6]. Anaerobic digestate on the other hand is capable of releasing the essential nutrients fast enough because of the metabolism of the nitrogen-fixing and phosphate-solubilizing organisms present in them [5,11]. As a result, various researchers have explored the production and utilization of organic fertilizers from various sources ranging from composting of food and agricultural wastes to anaerobic digestate [12-15].

Various researches have explored independently, the generation of biogas from abattoir waste [3] as well as the biofertilizer capabilities [5] but a holistic assessment of the biogas and biofertilizer potentials of abattoir waste seem to be non- existent. The absence of such studies will make it difficult to estimate the combined biogas and biofertilizer benefit accruing from the anaerobic digestion as a waste management alternative.

This study was therefore carried out to estimate the biogas and biofertilizer potential of cattle slaughterhouse wastes and to assess the waste treatment efficiency of the Anaerobic Digestion process.

2. MATERIALS AND METHODS

2.1 Sample Collection, Preparation and Anaerobic Digestion

Cattle paunch used as biomass feedstock in this study was obtained from Zaria Abattoir and transported to the research ground in the Department of Water Resources and

Environmental Engineering, Ahmadu Bello University, Zaria. The paunch was collected immediately after the animal was slaughtered and the rumen content removed. The paunch (30 kg) was thoroughly mixed with water in the ratio 1/1 (w/w) to form slurry. The feedstock was fed into 2.5 m^3 Digester occupying about 80% of the total volume. The digester valves were open prior to the loading to prevent negative pressure build up. Batch anaerobic digestion then took place for a retention period of 30 days. Operating parameters such as ambient and digester temperatures as well as pH were measured to monitor the stability of the digestion process. The temperatures were measured using 2/1°C thermometer while pH meter model pHS-2S (Shanghai Jinyke Rex, China) was used to measure the pH of slurry.

2.2 Assessment of Biogas Potentials

Daily biogas production was measured every evening using the calibration on the gasholder. The methods for the measurement of daily biogas production have been described previously in Alfa et al. [4] and Owamah et al. [2]. The total volume of biogas produced over the 30 days retention period was used to estimate the annual biogas potential for one cow using the eqn. [1].

$$Biogas\ potential = \frac{Total\ Vol.of\ Biogas\ Produced}{Retention\ Time} \times 365\ days \qquad (1)$$

The methane content of the biogas was measured by gas chromatography (GC) (Agilent Technologies 6890N, Ca, USA) described in detail previously by Owamah et al. [2].

2.3 Preparation of Digestate Compost and Assessment of Biofertilizer Potentials

2.3.1 Composting of digestate

On completion of the 30 days digestion period, the digestate was removed from the digester and cured for 20 days at the prevailing average ambient temperature of 37±3°C in order to form a simple compost of the digestate.

2.3.2 Assessment of growth and yield of maize

A 4 x 4 experimental design was conducted to assess the effectiveness of the application of digestate compost in the production of maize compared to the use of Urea fertilizer and a combination of digestate compost and urea. 16 number plots (1 m x 1 m) spaced 1 m apart were obtained in the research fields of Samaru College of Agriculture, Division of Agric Colleges, Ahmadu Bello University, Zaria, cleared, ploughed and properly harrowed for the cultivation of maize. The plots were designated in quadruplicates as Control, Compost, Urea and Compost + Urea indicating the respective treatments. The Control plots were to serve as reference in establishing whether the treatments had any impact on the crop yield or not.

The digestate compost was applied to four plots designated as Compost following standard methods of fertilizer applications for the production of maize while the Urea (Chemical fertilizer) was applied to four plots designated as Urea, digestate compost and Urea combined in ratio 1:1 was applied to four plots designated as Compost + Urea. The last four were left without fertilizer application to serve as control.

After the preparation of the respective plots, three seeds each of Maize (*Zea mays*) were planted on the 16 plots spaced 50 cm apart (intra and intra rows) in accordance with IPNI [16]. The date of germination was noted for all the plots while plant heights and the widths of stems were measured daily for the first three days after germination then weekly thereafter until the plants started tasselling. The crop was harvested on maturity. The number and weight of cobs produced for each plot were taken and recorded.

The results obtained were subjected to a Two Way Analysis of Variance (2 Way ANOVA) at 95% Confidence level using MINITAB 14.12.0 Statistical Software.

2.4 Assessment Waste Treatment Efficiency of the Anaerobic Digestion Process

2.4.1 Physicochemical analysis

Physicochemical analysis of the feedstock and digestate was carried out to ascertain the efficiency of the anaerobic digestion process in stabilizing the waste. The parameters tested are Total Solids, Volatile Solids and Chemical Oxygen Demand. The tests were arried following standard procedures described previously [5,11,17].

2.4.2 Microbial analysis

Samples were collected from the feedstock before digestion and from the digestate after digestion respectively for the isolation and assessment of the microbial population.

Enumeration of microbial population of the feedstock and digestate was carried out by standard plate count. MacConkey agar, Fastidious Anaerobic agar, Eosin Methylene Blue (EMB) agar, and Nutrients agar plates were used for bacteria enumeration. The incubation of MacConkey, EMB and Nutrient agar plates was done for 24–48 hours at 37°C. The incubation of Fastidious Anaerobic agar plates on the other hand was done at 37°C for 7 days in an anaerobic jar (Oxoid) containing a moistened pack of gas generating kit (Bio-oxoid). Individual colonies were purified and identified by morphological and biochemical techniques described previously [18]. Details of the isolation methods have been fully described previously [3,19]. Three counts were used to determine each mean value reported in this study.

3. RESULTS AND DISCUSSION

The results obtained in this study are presented and discussed in the following sections.

3.1 Biogas Production from Abattoir Cattle Paunch

The results of the daily biogas production and the cumulative biogas production over the 30 days retention period are presented in Fig. 1.

The results are further summarized in in Table 1. The results reveal that the total volume of biogas produced over the 30 days retention period is 0.61 m^3 while the average daily biogas, yield, average yield per kg, average daily yield per kg and the estimated methane contents are 0.0203 m^3/day, 0.00068 m^3//kg/day and 63% respectively.

These results imply that for an estimated 30 kg rumen content of a mature cow slaughtered at the abattoir, the total annual biogas potential is estimated as follows.

$$Biogas\ potential = \frac{0.61028}{30} \times 365\ days$$
$$= 7.425\ m^3$$

The possible volume therefore depends on the number of cattle slaughtered per day at the abattoir.

3.2 Performance of Biofertilizer Potentials of Digestate Compost for the Production of Maize

Based on the percentage reduction in total solids, the total weight of digestate compost obtained was estimated at 14.66 kg.

The box plots of the results of the plant heights, plant diameter, average growth rate, number of cobs and weight of cobs by the respective treatments and plots are shown in Figs. 2-6.

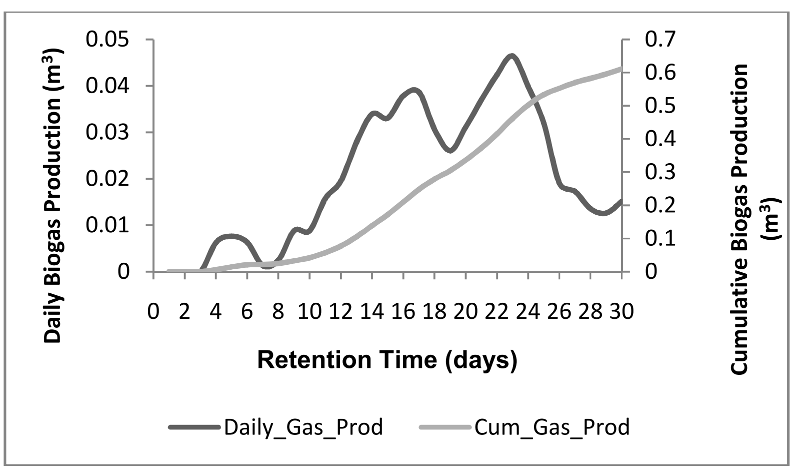

Fig. 1. Daily and cumulative biogas production from abattoir cow paunch

Table 1. Results of the biogas production from cattle paunch

Total volume of biogas (m^3)	Average biogas yield per day (m^3/day)	Average yield per kg of paunch (m^3/kg)	Average daily yield per kg of slurry (m^3/kg/day)	Methane content (%)
0.61028	0.02034	0.01795	0.00068	62.98

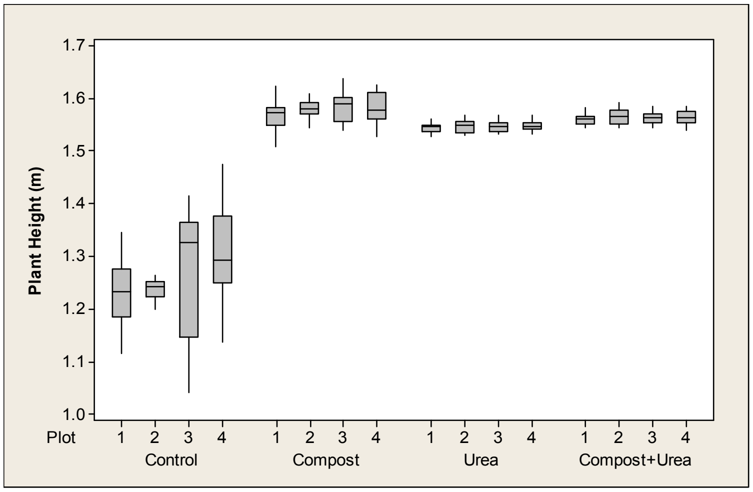

Fig. 2. Box plot of plant heights by treatments and plots

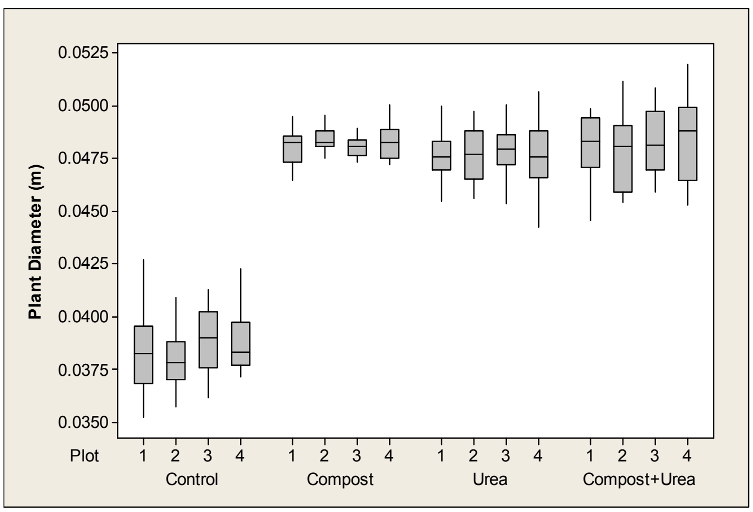

Fig. 3. Box plot of plant diameters by treatments and plots

The box plots show that all the treatments had better height performances than the control. The compost treated plots appear to have the best performance with respect to plant heights (Fig. 2) and was closely followed by the Compost + Urea treated plots and the Urea treated plots. The same assertion is true for plant diameter (Fig. 3), average growth rate (Fig. 4) and number of cobs (Fig. 5). The weight of cobs showed slightly different characteristics (Fig. 6). The range of results seems to be wider than it was for other parameters.

Meanwhile, the results of the Two Way ANOVA performed showed that there was significant different in all the parameters for the respective treatments with a *P*-value of 0.000 in each case (Table 2).

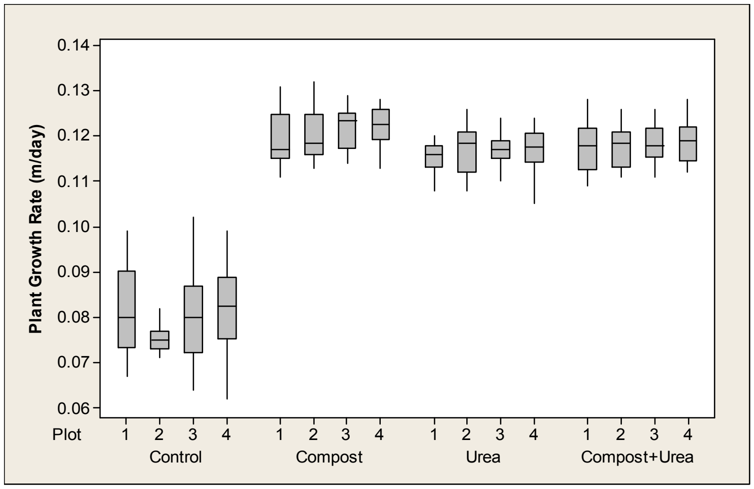

Fig. 4. Box plot of plant growth rates by treatments and plots

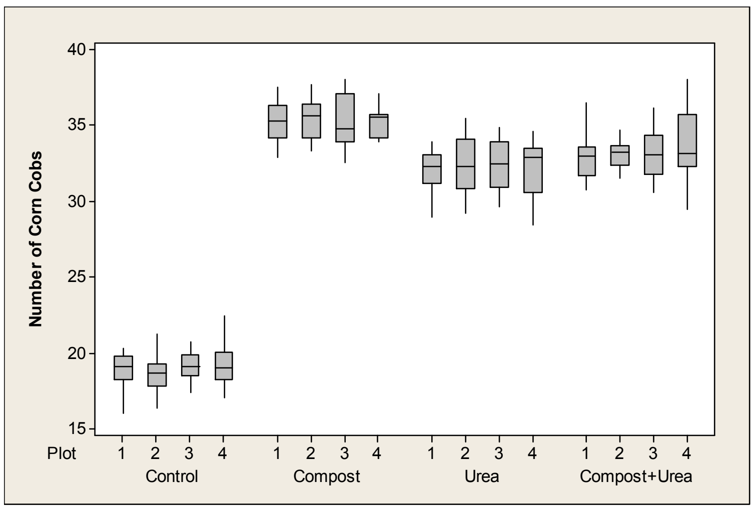

Fig. 5. Box plot of number of cobs by treatments and plots

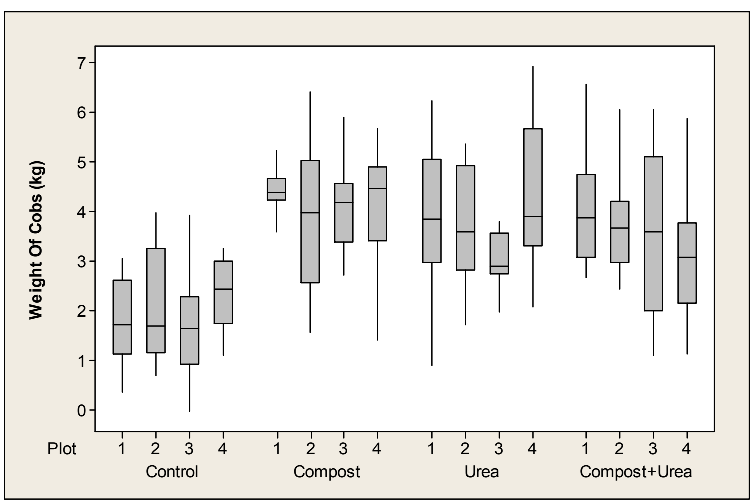

Fig. 6. Box plot of weight of cobs by treatments and plots

Table 2. *P*-values obtained from the Two-Way ANOVA performed at 95% Confidence level

Source	Plant height	Plant diameter	Average growth rate	Number of cobs	Weight of cobs
Treatment	.000	.000	.000	.000	.000
Plot	.035	.298	.103	.708	.155
Interaction	.051	.918	.322	.846	.070

The results on Table [2] further reveal that apart from the plant height, there was no significant difference between the plots for all the parameters (*P-values* of .298, .103, .708 and .155 respectively for plant diameter, average growth rate, number of cobs and weight of cobs). The plant heights showed a significant different between the plots with a *P*-value of 0.035. The interactions between the plots and treatments on the other hand showed no significant difference for all the parameters with *P*-values of .051, .918, .322, .846 and .070 for plant height, plant diameter, average growth rate, number of cobs and weight of cobs respectively.

Furthermore, a comparison of results obtained from each treatment with the control is presented in Table 3.

All the 95% confidence intervals obtained for the respective parameters by treatments did not include zero which further confirms that there was actually significance between the results obtained for the respective treatments. Based on the confidence intervals obtained for all parameters, the performance of the compost with the urea treatments were very close to each which implies that the digestate compost could effectively replace Urea fertilizer in maize production. The results obtained in this study show similar characteristics with studies of Igboro et al. [20] which compared the digestate compost with NPK fertilizer for the cultivation of maize and guinea corn. Their results also showed significant difference between the treatments.

Table 3. Comparison of the crop growth rate and yield for respective treatments

Treatment	Mean ± SD	95% Confidence Interval)	*P*-Value
Plant height (m)			
Compost	1.5775±0.0261	0.294815 - 0.341002	.000
Urea	1.5458±0.0099	0.263941 – 0.308450	.000
Compost + Urea	1.5633±0.0121	0.281338 – 0.326162	.000
Control	1.2596±0.0890	-	-
Plant diameter (m)			
Compost	0.0482±0.0007	0.009320 – 0.010177	.000
Urea	0.0477±0.0013	0.008768 – 0.009840	.000
Compost + Urea	0.0482±0.0017	0.009179 – 0.010330	.000
Control	0.0385±0.0016	-	-
Av. growth rate (m/day)			
Compost	0.1209±0.0051	0.038032 – 0.043450	.000
Urea	0.1168±0.0044	0.033920 – 0.039187	.000
Compost + Urea	0.1184±0.0048	0.035488 – 0.040837	.000
Control	0.0802±0.0094	-	-
Number of cobs			
Compost	35.35±1.39	15.9573 – 16.8660	.000
Urea	32.18±1.66	12.7604 – 13.7537	.000
Compost + Urea	33.28±1.66	13.8435 – 14.8567	.000
Control	18.93±1.20	-	-
Weight of cobs			
Compost	4.150±1.020	1.83482 – 2.52665	.000
Urea	3.750±1.280	1.36589 – 2.15224	.000
Compost + Urea	3.570±1.270	1.21615 – 2.00104	.000
Control	1.966±0.944	-	-

SD = Standard Deviation

Table 4. Treatment efficiency of the anaerobic digestion process

Parameters	TS (g/kg)	VS (g/kg)	COD (gO_2/kgTS)	*E. coli*	*Enterobacteriaceae*
Feedstock	158.21±13.96	34.33±6.31	872.38±41.34	$9.28x10^5$±1.31	1.25E+04
Digestate	74.15±11.73	18.15±2.09	618.53±57.69	$1.23x10^5$	1.09E+03
% Reduction	53.13	47.12	29.10	86.75	91.28
Efficiency %	63.86				

Mean ± Standard deviation; N=3 for each parameter measured

Table 5. Results of biochemical characterization of isolates of feedstock and digestate and microbial profile

Source	Isolate code	Gram reaction	Biochemical test						Organism
			Indole	MR	VP	Citrate	H_2S	Motility	
Feedstock	FS01	-ve	+	+	-	-	-	-	*E. coli*
	FS02	-ve	-	+	-	-	-	-	*Shigella spp*
	FS03	-ve	-	+	-	+	+	+	*Salmonella spp*
	FS04	-ve	-	-	+	+	-	-	*Klebsiella spp*
Digestate	DG01	-ve	-	+	-	+	+	+	*Salmonella spp*
	DG02	-ve	+	+	-	-	-	-	*E. coli*
	DG03	-ve	-	-	+	+	-	-	*Klebsiella spp*

Key: MR= Methyl Red; VP=Voges Prospkeur; H_2S= Hydrogen Sulfide

3.3 Waste Treatment Efficiency

3.3.1 Physicochemical characteristics microbial profile of feedstock and digestate

The physicochemical characteristics of the feedstock and digestate as well as their respective percentage reductions are presented in Table 4. A 53.13% reduction in total solids was achieved while a reduction of 47.12% was achieved for the volatile solids. The reduction in COD was 29.10% while that for *E. coli* and *Enterobacteriaceae* were 86.75% and 91.28% respectively. The overall efficiency of the treatment processing was estimated as 63.86% which is above average. The treatment efficiency obtained herein showed similar trend with the previous studies of Alfa et al. [5].

Furthermore, the results of the biochemical characterization of isolates of feedstock and digestate are shown in Table 5. The results show that *Shigella spp.* was effectively removed by the anaerobic digestion process. The presence of *Klebsiella spp.* futher confirms the potential of the digestate compost a good biofertilizer since it's a great nitrogen-fixing bacteria [21-23].

4. CONCLUSION

The study has demonstrated that a total of 7.43 m^3 of biogas could be produced from the rumen content of one matured cow slaughtered at an abattoir annually. The yield of maize from the digestate compost-treated plots were comparable with those of the urea-treated plots demonstrating that digestate compost could be a good substitute for chemical fertilizers such as Urea. However, it should be used with caution as some pathogens such as *Salmonella spp.* were implicated in the digestate. The study therefore recommends the use of digestate compost of cattle paunch for soil fertility improvement. It also recommends that further studies on possible modifications of the anaerobic digestion process for complete removal of *Salmanella spp.* be carried out.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://prh.sdiarticle3.com/review-history/20448