NUTRIENT VALUE IN THE EFFLUENT OF HUMAN EXCRETA AND FRUIT WASTE IN TWO FIXED DOME BIOGAS PLANTS

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ABSTRACT

The aim of the study was to investigate the nutrient value and heavy metals in the effluent of human excreta (HE) and fruit waste (FW) in two biogas plants in the Greater Accra region of Ghana. The research was conducted under mesophyllic conditions within a short hydraulic retention time of 21 days. Two samples each of the influent and effluent were collected with sterilized plastic containers from each digester from January, 2011 to May, 2011. The mean, standard error (SE) and percentage increase/reduction in the effluent for each parameter were computed for both digesters. The study found that the process of anaerobic digestion has a transformation effect on nutrients. After the process of anaerobic digestion, ammonium-nitrogen (NH_4-N) in the effluent of both human excreta and fruit waste were found to increase by 25.2% and 24.35% respectively. With respect to the influent, total potassium (K_2O) of the effluent of human excreta increased by 2.0% and that of fruit waste by 2.1%. Total phosphate (P_2O_5) increased by 1.7% in the effluent of human excreta whiles 1.8% total P_2O_5 was found to increase in the effluent of the fruit waste. Dry matter (DM) content reduced more than half in both effluents whiles pH increased relatively thereby influencing the availability of NH4-N content in the effluents. Heavy metals such as cadmium (Cd), lead (Pb) and zinc (Zn) in both effluents (human excreta and fruit waste) remained unchanged but traceable and met acceptable standards for disposal into the environment.

Keywords: human excreta, fruit waste, influent, effluent, anaerobic digestion, biogas plant.

INRTODUCTION

Anaerobic digestion in biogas plants is the breakdown of organic waste by putrefactive bacteria in the exclusion of air. Anaerobic digestion (AD) has been successfully applied in recycling of bio-waste and agricultural wastes, industrial wastewater treatment, stabilisation of sewage sludge, onsite sanitation and landfill management (Margareta *et al*., 2006). The products of AD include biogas and liquid nutrient enriched effluent (digestate). This liquid effluent contains high proportion of nitrogen (Berglund, 2006) and significant reductions of pathogenic organisms (salmonella and clostridium) as well as disease causing indicator organisms including fecal and total coliforms (Issah *et al*., 2012).

During anaerobic conditions, organic forms of nitrogen (N) are converted into ammonium-nitrogen (NH_4-N) of about 26% (Smith *et al*., 2007) and 20% (Frost and Gilkinson, 2010) in the effluent compared to the influent. Also, ammonium fraction of total nitrogen (TN) according to Chambers and Nicholson (2004) increases by about 50% in the effluent of cattle slurry and 60% in the effluent of pig slurry. Changes in slurry phosphorus (P) availability may also occur as a result of the release of P from organic forms during digestion, leading to an increase in water-soluble P fraction. Furthermore, high proportions of P and potassium (K) in animal diets are excreted. Animal manures and slurries are therefore rich in plant nutrients. After AD process, these elements are retained in the effluent and become bio-available for plant uptake. This is also the case for many other types of AD feedstock, making the effluent after anaerobic digestion process a valuable bio-fertiliser (Lukerhust, *et al*., 2010). Nonetheless, there may be increase in the vulnerability of effluent P losses to surface waters due to run-off (Smith *et al*., 2007). Notwithstanding the availability of plant nutrients in the effluent, pH plays an important role during the digestion process as well as stabilizing the effluent NH_4-N. The range for this to occur lies between 7.0 and 7.5 for both digester performance and stabilizing NH_4-N in the effluent (Fry, 1973).

Virtually all effluents from biogas plants after AD are liquid and contain approximately 2-7% dry matter (Berglund, 2006). Dry matter (DM) reduction of AD effluent with respect to the influent content lies between 50 and 75% (Vetter *et al*., 1987; Drouillon *et al*., 1997). The reduction of DM in the effluent might be due to the loss of organic carbon in the formation of methane (CH_4) and carbon dioxide (CO_2) during biogas production (Fry, 1973). In terms of metals reduction in the effluent after AD, Monnet (2003) reported that heavy metals reduction in anaerobic digested effluent is not feasible. This study therefore sought to highlight and compare the extent of nutrients and heavy metals transformations in the effluent of human excreta (HE) and fruit waste (FW) in two fixed dome biogas plants in order to ensure that the effluent is safe for disposal into water bodies, use in aquaculture or for irrigating crops.

MATERIALS AND METHODS

Study area

The research was conducted in two anaerobic digesters: a 8 m^3 fixed dome twin digesters for HE at Ashaiman, located on latitude 5^0 42' 00"N and longitude -2^0 00"W and a 50 m^3 fixed dome digester for FW at the Food Research Institute, Accra located on latitude 05°35'N and longitude 00°06'W both in the Greater Accra Region of Ghana. The area falls within the dry Coastal Savannah agro-ecological zone with temperature ranging from 20-30°C. The annual rainfall ranges between 635 - 1, 140 mm (Issah *et al.*, 2012). The Greater Accra region generates between 1, 500 -1, 800 tonnes of waste daily and an average of 1, 200 tonnes is collected per day by waste management companies. The remaining wastes find their way into the drainage systems and other open spaces (Issah *et al*., 2012).

Feed stock and organic loading rate (OLR)

Prior to the research, the digesters were already inoculated with cow dung. Feed stock for the digester treating human excreta was fed with only human excreta and urine per day. The fruit waste used was macerated pineapple and mango peels. Each digester was loaded with 2.9 Kg VS / m^3-day to reconcile with the recommended organic loading rate of 3.3 kg VS / m^3-day for effective bioconversion (MAC, 2005). The OLR was calculated for each digester using equation (1).

OLR = Organic material added (Kg VS) / digester volume (m^3/day) (1)

Analytical methods

In all, two samples each of the influent and effluent were collected with sterilized plastic containers from each digester every 21 days starting from January, 2011 to May, 2011. The samples were stored in a cold box at 4 ^oC and analyzed for Total Kjeldal Nitrogen (TKN), NH4-N, P_2O_5, K_2O, pH, DM, Pb, Zn and Cd at the Soil Research Institute of the Council for Scientific and Industrial Research Laboratory, Kumasi, Ghana. The parameters were determined as follows:

Total Kjeldal Nitrogen (TKN)

1.0 g sample was digested in 10 ml H_2SO_4, distilled with 20 ml NaOH into a flask containing boric acid and titrated with sulphuric acid to a violet end point (Koopmann, 2008a).

Ammonium-Nitrogen (NH_4-N)

10.0 ml KCl was added to 3.0 g sample in an extraction bottle. The extract was filtered through 8-12 µm filter and NH_4-N determined using EN ISO 11732 (Koopmann, 2008b).

Total Phosphate (Total P_2O_5)

3.0 g sample was weighed and moistened with 1 ml water, swirled with 21 ml of hydrochloric acid followed by 7 ml of nitric acid plus boiling aids and heated for 2 hours, allowed to cool, filtered and phosphorus measured by ICP-OES (Koopmann, 2008c)

Ortho Phosphate (Ortho P_2O_5 in mg/l)

2.5 g sample and 50 ml of 0.5 M sodium bicarbonate (pH of 8.5) solution was shaken for 30 minutes, filtered and orthophosphate portion determined at 630 nm using Technicon Auto Analyzer II (Molina, 2009).

Total Potassium (Total K_2O)

6.0 ml nitric acid was added to 300 mg sample and predigested. It was re-digested for 10 minutes and cooled for 2 minutes. Two (2) ml 30% H_2O_2 solution was then added and digested again at 140 ^oC for 60 minutes, cooled for 30 minutes, diluted to 100 ml with de-ionized water and analyzed using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) at 404.7 nm (Holstege *et al*., 2010).

Dry matter (DM)

10 g sample was placed on a foil plate and dried in an oven to a temperature of 105 ^oC. DM was calculated using equation (2).

DM (%) = (Final weight (g) / Initial weight (g)) x 100 (APHA, 1998). (2)

pH

The pH was determined using a pH meter. The glass probe of the meter was dipped to a depth of about 5cm and values read directly on the screen. The meter was then sterilized with de-ionized water and the procedure repeated for other samples.

Metals

1.0 g sample was digested with 20.0 ml nitric acid (1:1), heated at 120 ^oC for 30 minutes, cooled, filtered and the metals determined by Inductive Couple Plasma-Atomic Emission Spectrum (ICP-AES) at 226.502 nm for Cd, 220.353nm for Pb and 213.856nm for Zn.

Statistical analysis

The mean, standard error (SE) and percentage increase/reduction were calculated for each parameter using Microsoft Excel and SPSS.

RESULTS AND DISCUSSIONS

Table-1 presents the results of the influent and AD effluent of human excreta whiles Table-2 presents the results of the influent and AD effluent of fruit waste. Results from the research in Table-1 recorded a mean total Khedjal Nitrogen (TKN) in the influent of HE was 8.30 mg/l and 8.98 mg/l in the effluent representing 8.2% increase in the effluent. The standard errors were 0.45 and 0.33, respectively for the influent and effluent. The mean NH_4-N in the influent of human excreta was 5.15 mg/l with SE of 0.73 and 6.45 mg/l with SE of 0.12 in the effluent representing 25.2% increase in the effluent. Furthermore, the percentage NH_4-N content of Total Nitrogen (TN) was 62.0% in the influent and 71.8% in the effluent. The content of NH_4-N after the anaerobic digestion process might be due the breakdown of organically bound proteins in the human excreta. This is consistent with the findings of Berglund (2009) and Smith *et al.* (2007).

In Table-2, TKN in the influent of fruit waste was 4.50 mg/l with SE of 0.93 and 4.60 mg/l with a SE of 0.15 in the effluent representing 2.2% increase in the effluent. NH4-N of fruit waste increased from 2.05 mg/l with SE of 0.34 in the influent to 2.55 mg /l with SE of 0.33 in the effluent representing 24.4% increase in the effluent after the anaerobic digestion process. The percentage NH_4-N of TKN in fruit waste influent recorded 45.6% and 55.4% in the effluent. This is quite consistent with the findings of Smith *et al.* (2007). The results showed that the effluent of human excreta contain more TKN and NH_4-N than the effluent of fruit waste. This might be due to organically bound proteins in human excreta than in fruit waste. Nonetheless, both effluents were within the Ghana Environmental Protection Agency (GEPA) acceptable limits of 1-10 mg/l for disposal or use in agriculture.

Table-1. Results of macro-nutrients and some heavy metals in the influent and effluent of human excreta.

Parameter	**Influent**	**SE**	**Effluent**	**SE**	**Increase/Reduction** (%)
TKN (mg/l)	8.30	0.45	8.98	0.33	8.2
NH_4-N (mg/l)	5.15	0.73	6.45	0.12	25.2
NH_4-N (% of TN)	62.0	-	71.8	-	-
Total P_2O_5 (mg/l)	1.15	0.46	1.17	0.30	1.7
OrthoP_2O_5 (mg/l)	1.01	0.82	1.03	0.61	2.0
% Ortho of P_2O_5	87.8	-	88.0	-	-
Total K_2O	2.45	0.22	2. 50	0.41	2.0
DM (%)	13.80	0.66	5.25	0.30	61.8 (reduction)
pH	5.75	0.13	7.25	0.27	26.1
Cadmium (Cd)	0.0249	0.35	0.0249	0.35	-
Lead (Pb)	0.0046	0.34	0.0046	0.33	-
Zinc (Zn)	1.246	0.53	1.246	0.54	-

SE: Standard Error, TKN: Total Kjeldal Nitrogen, NH_4-N: Ammonium-Nitrogen, P_2O_5: Phosphate, DM: Dry Matter, K_2O: Potassium

Total P_2O_5 in the influent of the human excreta (Table-1) was 1.15mg/l with SE of 0.46. After the process of AD, 1.17 mg/l total P_2O_5 with SE of 0.30 was recorded in the effluent representing a 1.7% increase in the effluent. For the fruit waste, total P_2O_5 was 1.10 mg/l with SE of 0.70 in the influent and 1.11 mg/l with SE of 0.67 in the effluent representing an increase of 0.9% in the effluent after the anaerobic digestion process.

The orthophosphate (water soluble portion of total phosphate) in the influent of human excreta recorded was 1.01 mg/l with SE of 0.82 in the influent and 1.03 mg/l with SE of 0.61 in the effluent representing 2.0% increase in orthophosphate in the effluent after the anaerobic digestion process. For fruit waste, the orthophosphate in the influent was 0.61 mg/l with SE of 0.20. This increased to 0.62 mg/l with SE of 0.19 representing an increase of 1.6% orthophosphate in the effluent.

Orthophosphate fraction of total P_2O_5 in the influent of human excreta was 87.8% and 88.0% in the effluent whiles 55.5% and 53.4% was found in the influent and effluent respectfully in the fruit waste. The results showed a lower P_2O_5 and orthophosphate (water soluble phosphorus) in the effluent of fruit waste compared to human waste. This may be the result of the release of more organic phosphorus in human excreta than in fruit waste during the digestion process. The findings however agrees with the assertion of Schenkel (2009) that biogas effluents generally contain low phosphorus and need to be supplemented with super phosphate fertilizer. In terms of discharge into water courses or use in agriculture/aquaculture, the total P_2O_5 in the effluent of both HE and FW are within the GEPA maximum acceptable level of 2.0 mg/l.

Total K_2O in the influent of the human excreta (Table-1) recorded a value of 2.45 mg/l with SE of 0.22. After the process of anaerobic digestion, the effluent was found to contain 2.5 mg/l total K_2O with SE of 0.41 representing a percentage increase of 2.0%. The results of the digester treating the fruit waste as shown in Table-2, recorded 3.82 mg/l of total K_2O in the influent with SE of 0.28 and 3.90 mg/l K_2O with SE of 0.39 in the effluent, representing a 2.1% increase.

The results therefore showed that, fruit waste contained more total K_2O in the effluent of fruit waste than in the effluent of human excreta. This might be due to the concentration of potassium in plant cells and fruits than in human excreta.

The pH of the influent of human excreta recorded a value of 5.75 with SE of 0.13. As a result of the anaerobic digestion process, pH of the effluent increased to 7.25 with SE of 0.27. In the influent of the fruit waste, pH was 4.38 with SE of 0.79. This increased to 6.75 with

SE of 0.79 in the effluent. The finding however, revealed that pH of anaerobic digested effluents is higher than pH of undigested wastes which reflects similar findings by Smith *et al.* (2007). The high pH value recorded in the digester treating human excreta reflects the high content of NH_4-N in the human excreta (Table-1). This is because ammonia is more alkaline than acidic, hence its influence on the pH value during anaerobic digestion. Likewise, the lower pH in the digester treating the fruit waste (Table-2) reflects the high acidity content in fruit peels and crowns used as influent. In terms of environmental discharge or agriculture/aquaculture utilization, the pH in the effluent of human excreta (7.25) and that of the fruit waste (6.74) were within the GEPA limit of 5.0-9.0.

Table-2. Results of macro-nutrients and some heavy metals in the influent and effluent of fruit waste.

Parameter	**Influent**	**SE**	**Effluent**	**SE**	**Increase/Reduction** (%)
TKN (mg/l)	4.50	0.93	4.60	0.15	2.2
NH_4-N (mg/l)	2.05	0.34	2.55	0.33	24.4
NH_4-N (% of TKN)	45.60	-	55.4	-	-
Total P_2O_5 (mg/l)	1.10	0.70	1.11	0.67	0.9
OrthoP_2O_5 (mg/l)	0.61	0.20	0.62	0.19	1.6
% Ortho of P_2O_5	55.5	-	53.4	-	-
Total K_2O	3.82	0.28	3.90	0.39	2.1
DM (%)	17.4	0.60	7.25	0.15	58.4 (reduction)
pH	4.38	0.79	6.75	0.79	54.1
Cadmium (Cd)	0.066	0.45	0.066	0.43	-
Lead (Pb)	0.146	0.15	0.146	0. 16	-
Zinc (Zn)	2.490	0.55	.490	0.56	-

SE: Standard Error, TKN: Total Kjeldal Nitrogen, NH_4-N: Ammonium-Nitrogen, P_2O_5: Phosphate, DM: Dry Matter, K_2O: Potassium

The DM content of the influent of human excreta was 13.80% with SE of 0.66. After the process of anaerobic digestion, the effluent was found to contain 5.25% DM with SE of 0.30 representing 61.8% reduction. Also, the fruit waste influent recorded a value of 17.4% DM with SE of 0.60. This reduced to 7.25% DM with SE of 0.15 representing a reduction of 58.4% of DM in the effluent. The results therefore show that anaerobic digested effluent has lower DM content than the influent. This is consistent with similar findings by Vetter *et al.* (1987) and Pfundtner (2002).

The heavy metals (Cd, Pb, and Zn) in the influents of both human excreta and fruit waste were quite traceable and remained unchanged in their respective effluents after the process of anaerobic digestion as reported by Monnet (2003). This may probably be due to the inability of putrefactive bacteria to degrade these elements during hydrolysis, acetogenesis and methanogenesis. Notwithstanding this, the levels of Cd, Pb and Zn did not exceed the Ghana Environmental Protection Agency regulations for disposal of effluents (5.0 mg/l for Cd, 0.1mg/l for Pb and 10.0 mg/l for Zn).

CONCLUSIONS

The results of this study illustrates that anaerobic digestion in biogas plants has nutrients transformation effect on organic waste. The findings showed that macronutrients (TKN, NH_4- N, P_2O_5 and K_2O) in the effluents of both waste were almost the same as in the influents but bio-available for plants uptake. The nutrient availability in the effluent of human excreta after twenty-one (21) days retention period stood as 25.2% increase in NH_4-N, 8.2% increase in TKN, 2.0% increase in K_2O and orthophosphate, 1.7% increase in total P_2O_5 and 61.8% reduction in DM. Likewise, the effluent of fruit waste within the same retention period was found to contain 24.4% increase in NH_4-N, 2.2% increase in TKN, 2.1% increase in total K_2O, 1.6% increase in Ortho P_2O_5, 0.9% increase in P_2O_5 and 58.4% reduction in DM. Both effluents were found to contain more nitrogen as a result of the near alkaline pH recorded. Nevertheless, phosphate in both wastes was low. The heavy metals (Cd, Pb and Zn) did not change in the effluents after the digestion process and was within acceptable levels for disposal. It is however recommended that, disposal of the effluents should be channeled into farmlands where soils are deficient in nitrogen for phytoextraction or in fish ponds to increase algae yield for fish.

ACKNOWLEDGEMENT

We wish to thank the staff of the Soil Research Institute (SRI) of the Council for Scientific and Industrial Research (CSIR), Kumasi-Ghana for their support during the analysis of samples. We are deeply grateful.

REFERENCES

America Public Health Association (APHA). 1998. Standard Methods for the examination of Water and Waste water, 20th edition, APHA, Washington DC.

Berglund M. 2006. Biogas Production from a System Analytical Perspective. PhD Thesis. Lund University, Lund, Sweden.

Chambers B. J. and Nicholson F. A. 2004. Manure Analysis Database. http://www.randd.defra.gsi.gov.uk.

Drouillon M., Mattheeuws B., Steenhoudt D., Willaert L. and Ghekiere G. 1997. Biological, physical and chemical properties of digestates and manure. http:// www. Northseabioenergy. Org/files/ 17397/ Magriet_ Drouillon_ppt.pdf.

Frost P. and Gilkinson S. 2010. First Year Performance Summary for Anaerobic Digestion of Dairy Cow Slurry at AFBI Hillsborough. http://www.afbini.gov.uk/afbi-ad-hillsborough-27-months-june-11.pdf.

Fry L. J. 1973. Methane Digesters for Fuel Gas and Fertilizer with Complete Instructions for Two Working Models, Santa Barbara, California, USA.

Holstege D., Price P., Miller R. O. and Meyer D. 2010. California Analytical Methods Manual for Dairy General Order Compliance -Nutrient Management Plan Constituents. http://anlab.ucdavis.edu/dairy-general-order-compliance.

Issah A., Aklaku E. D. and Salifu T. 2012. Comparative Study of Effluent for Pollution Indicators and Indicator Pathogenic Organisms from Anaerobic Digesters for Human and Fruit Wastes. ARPN Journal of Agricultural and Biological Science. 7(6): 416-420.

Koopmann R. 2008a. Determination of Kjeldahl Nitrogen in soil, bio-waste and sewage sludge. http://www.ecn.nl/docs/society/horizontal/STD6161_Kj-N.pdf.

Koopmann R. 2008b. Determination of ammonium and nitrate in soil, bio-waste and sewage sludge. http://www.ecn.nl/docs/society/horizontal/STD6162_NH4-N.pdf.

Koopmann R. 2008c. Total phosphorus in soil, biowaste and sewage sludge. http://www.ecn.nl/docs/society/horizontal/STD6163_TP.pdf.

Lukehurst C. T., Frost P. and Al-Seadi T. 2010. Utilization of digestate from biogas plants as bio-fertilizer. IEA Bio-Energy. pp. 5-16.

M. Elvaney Associates Corporation (MAC). 2005. Biogas conversion primer. http://www.bioconverter.com/technology/primer.htm.

Margareta P., Owe J. and Arthur W. 2006. Biogas Upgrading to vehicle fuel standards and grid injection, IEA Bio-energy. pp. 3-20.

Molina L. R. 2009. Available phosphorus (Olsen Phosphorus), Standard Operating Procedure. International Rice Research Institute (IRRI), Los Baños, Philippines.

Monnet F. 2003. An Introduction to Anaerobic Digestion of Organic Wastes. http://www.biogasmax.co.uk/media/introanaerobicdigestion__073323000_1011_24042007.pdf.

Pfundtner E. 2002. Limits and Merits of Sludge Utilization-Land Application. European Workshop on Impact of Waste Management Legislation on Biogas Technology, Tulln, Austria, September 12-14.

Schenkel Y. 2009. An integrated approach for biogas production with Agricultural wastes, Guidelines 2-Recommendations for AD sludge utilization as a bio-fertilizer in agriculture. pp. 4-18.

Smith K. A., Jeffrey W. A., Metcalfe J.P., Sinclair A. H. and Williams J. R. 2007. Nutrient value of digestate from farm-based biogas plants. http://www.ramiran.net/ramiran2010/docs/Ramiran2010_0171_final.pdf.

Vetter H., Steffens G. and Schröpel R. 1987. The influence of different processing methods for slurry upon its fertilizer value on grassland. http://www.cranfield.ac.uk/sas/cas/projects/page49589.html.