Tropentag 2014, Prague, Czech Republic
September 17-19, 2014

Conference on International Research on Food Security, Natural Resource Management and Rural Development
organised by the Czech University of Life Sciences Prague

A comparative study of energy productions from selected crop residues through anaerobic digestion at mesophilic temperature

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Introduction

Biogas technology offers a very attractive route to utilize certain categories of biomass for meeting partial energy needs. Biogas is produced from organic wastes by concerted action of various groups of anaerobic bacteria. According to Mclnerrney and Bryant (1981), the production of biogas involves the breaking down of complex polymers to soluble products by enzymes produced by fermentative bacteria which ferment substrate to short-chain fatty acids, hydrogen and carbon dioxide. Fatty acids longer than acetate are metabolized to acetate by obligate hydrogen producing acetogenic bacteria. The product of anaerobic digestion primarily are methane (CH_4) and carbon dioxide (CO_2), with varying amounts of water, hydrogen sulphide (H_2S), oxygen and other compounds. Biogas is utilized for the production of heat, Combined Heat and Power (CHP) and also as vehicle fuel. With the use of agricultural wastes through biogas technology, wastes from farms can be used for generating energy for brooding chicks, operating incubators and in boiler operations. Biogas could also be used as supplementary fuel in dual fuel engines and as well as in the drying, cooking, boiling and smoking of fish (especially catfish), taking into consideration the market value of smoked fish.

Organic wastes are known to have high energy potential, as indicated by Odeyemi (1995) who obtained biogas from palm oil effluents. Various agricultural residues had been used in the past in the production of biogas. There is availability of large amounts of non-plantation biomass resources in Nigeria for modern energy applications. The amount of residues generated in 2004 varies from 311,000 tonnes for oil palm shells to 14 million tonnes for sorghum straw. The residue availability for 2010 was projected to be about 80 million tonnes (Jekayinfa and Scholz, 2009). Energetically, the Nigerian economy can be disaggregated into industry, transport, commercial, household, and agricultural sectors. The household sector has consistently accounted for over half of Nigeria’s total domestic energy consumption. According to Akinbami (2001), the energy consuming activities in this sector are cooking, lighting, and operation of electrical appliances.

Table 1 presents the outputs of the major crops in Nigeria between 2000 and2004 as reported by FAO (2007), an indication of increasing quantity of residues that could be derived from them. The total potential residues from maize stalk, cassava peelings, plantains peelings, groundnuts straw, cowpeas shells, palm kernel shells, cassava stalks, palm kernel cake, groundnuts husks/shells, maize cob, oil palm empty bunches, plantains trunks/leaves, maize husk, and oil palm fiber available in Nigeria in 2004 was about 70 million tonnes (Jekayinfa and Scholz, 2009).

The Objectives of the Research were to:

i. determine the biogas potential (biogas yield) of maize stalk, maize cob and rice straw by means of batch experiment at mesophilic temperature (37^{o}C).
ii. Compare the biogas produced by the selected substrates for the purpose of establishing the one with the highest potential for biogas production.
iii. Compare energy productions of the selected residues.

Table 1: Yields of major crops in Nigeria (10^6 MT)

Major crop	Year				
	2004	2005	2006	2007	2008
Maize	5.57	5.95	7.10	6.72	7.53
Cassava	38.85	41.56	45.72	43.41	44.58
Millet	6.70	7.17	7.71	8.09	9.06
Plantain	2.42	2.59	2.79	2.99	2.73
Groundnuts	3.25	3.48	3.83	3.84	3.90
Sorghum	8.58	9.18	9.87	9.06	9.32
Oil palm	1.09	1.17	1.29	1.31	1.33
Palm kernel	1.07	1.23	1.25	1.28	1.28
Cowpeas	2.82	3.04	2.80	2.92	2.63

Data for crop production available from FAO statistics (see http://www.fao.org).

Materials and Methods

Maize plants were harvested from the Institute for Animal Breeding and Animal Husbandry (ABAH), Ruhlsdorf / Grosskreutz, Germany and stalks and cobs were separated for experimentation. All samples were kept in the laboratory at a temperature of +3°C after size reduction (Plate 1) prior to feeding into the digester. Samples of maize stalk (MS), Maize Cob (MC) and Rice Straw (RS) were taken to the laboratory for analysis. The amount of substrate and seeding sludge weighed into the fermentation bottles were determined in accordance to German Standard Procedure VDI 4630 (2004) using the equation 1:

$$\frac{oTS_{substrate}}{oTS_{seeding\,sludge}} \leq 0.5 \qquad (1)$$

Where:

$oTS_{substrate}$ = organic total solid of the substrate and;

$oTS_{seeding\ sludge}$ = organic total solid of the seeding sludge (the inoculum)

Biogas production and quality from maize stalks, Maize cobs and Rice straw were analyzed in batch anaerobic digestion test at 37°C according to German Standard Procedure VDI 4630 (2004). Batch experiments were carried out in lab-scale vessels and replicated twice as described by Linke and Schelle (2000). A constant mesophilic temperature of 37°C was maintained through a climatic chamber (Plate 2). Anaerobically digested material from a preceding batch experiment was used as inoculum in this study. 800g of the stabilized inoculum was mixed separately with *9.95, 11.70 and 7.53 g* of MS, MC and RS respectively for anaerobic digestion. The fermentation vessels were properly shaken each day in order to fully re-suspend the sediments and the scum layer. The biogas produced was collected in graduated gas sampling tube inserted in a confining liquid in the defined period of 30-40 days and was measured daily. This duration of the test fulfilled the criterion for terminating batch anaerobic digestion experiments given in VDI 4630 (daily biogas rate is less or equal to only 1% of the total volume of biogas produced up to that time). Methane contents of the gas produced were determined at least six times during the batch test using the gas analyzer, GA 2000 model. Biogas production of the inoculum without substrate was also recorded as a control. The biogas and methane yields were then calculated at the standard temperature and pressure (0^oC, 1013 mbar).

Plate 1: Size Reduction for effective fermentation

Plate 2: Batch Experimental set-up

Results and Discussion

Table 2 shows the results of the laboratory analysis of MS, MC and RS. The tested samples showed monophasic curves of accumulated biogas production. After a steep increase, biogas production decreased resulting in a plateau of the cumulative curve (Figures 1-4). The biogas yields from organic dry matter (oDM) of MS, MC and RS were found to be 357.10 l_N /(kg $_{oDM}$), 514.31 l_N /(kg $_{oDM}$) and 324.54 l_N /(kg $_{oDM}$) respectively after 34 days digestion time. Methane yields (oDM) of MS, MC and RS were also found to be 222.39 l_N CH_4/(kg $_{oDM}$), 298.39 l_N CH_4/(kg

$_{oDM}$) and 211.30 $l_N CH_4/(kg_{oDM})$ respectively. The Biogas/methane yields from fresh mass (FM) of MS, MC and RS were found to be 147.59 $l_N /(kg_{FM})$ / 91.91 $l_N CH_4/(kg_{FM})$, 180.65 $l_N /(kg_{FM})$ / 104.81 $l_N CH_4/(kg_{FM})$ and 177.29 $l_N /(kg_{FM})$ / 115.43 $l_N CH_4/(kg_{FM})$. MS, MC and RS Maize stalk was found to have methane concentrations of 61.90, 58.02 and 65.11% respectively. Table 3 presents energy productions from MS, MC and RS.

Table 2: Results of laboratory analysis of the selected crop residues and the inoculum

Parameters	Maize stalk	Maize cob	Rice Straw	Inoculum
Dry Matter, DM (%)	45.54	36.10	74.68	2.13
Organic Dry Matter, oDM (%DM)	90.75	97.30	73.15	48.25
Organic Dry Matter (%FM)	41.33	35.13	54.63	1.03
NH4-N (g/kgFM)	<2	<2	0.19	0.31
N_{kjel}, g/kgFM	3.59	10.17	1.51	0.85
Pmg/kg TS60°	1366.6	1510.1	584.8	306.6
K %DM	1.22	1.27	1.18	15.50
Crude Fibre (%DM)	39.07	28.32	33.33	4.43
Ph	6.40	7.87	5.22	8.16
Conductivity	0.744	1.378	0.185	11.56
Fat (%DM)	1.61	1.14	0.39	
Ethanol (g/l)	<0.04	0.12	0.04	<0.04
Propanol	<0.04	<0.04	<0.04	<0.04
Total Acetic Acid	0.17	0.88	0.84	0.33
Carbon (%DM)	44.41	36.55	46.33	-

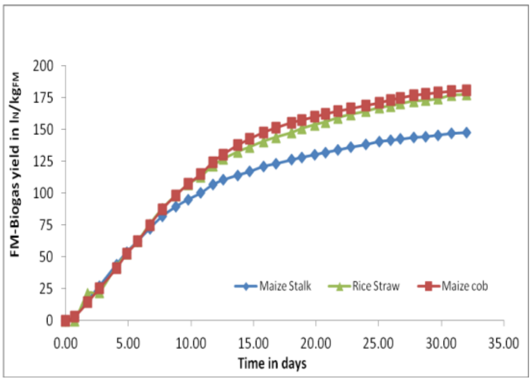

Figure 1: Daily Fresh-mass Biogas yield of MS, MC and RS

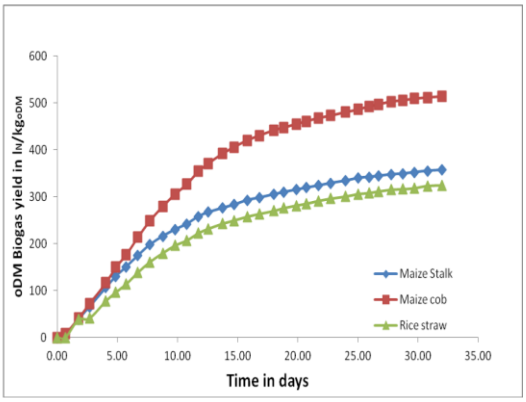

Figure 2: Daily oDM Biogas yields of MS, MC and RS as Substrates

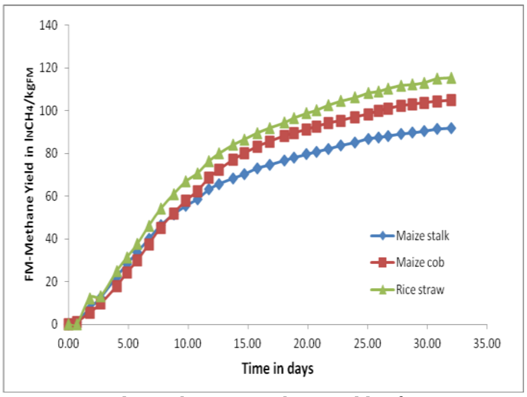

Figure 3: Daily Fresh-Mass Methane yields of MS, MC and RS

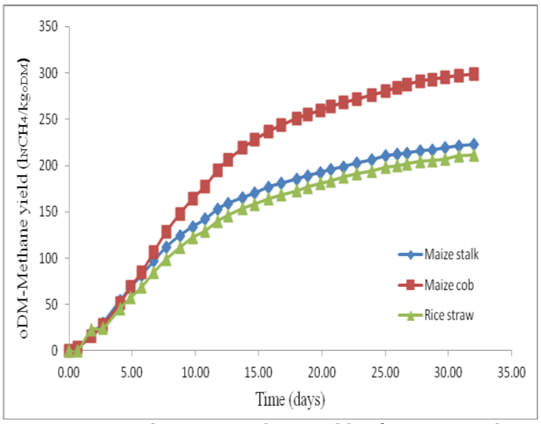

Figure 4: Daily oDM- Methane yields of MS, MC and RS

Table 3 : Energy productions from MS,MC and RS

Substrate	Biogas yield (m^3/kgoDM)	Energy (MJ)
Maize stalk	0.357	9.35
Maize cob	0.514	13.47
Rice straw	0.325	8.52

Note: Energy per cubic meter of biogas=26.2MJ (Nielson *et al.*, 2007 and Anunputtikul and Rodtong, 2007).

Conclusions and Outlook

From the results obtained, the following conclusions can be drawn

- Maize stalk (MS), maize cob (MC) and rice straw (RS) are good substrates for anaerobic digestion.
- The biodegradability of maize cob was the highest with biogas and methane potentials of *514.31 L/(kg $_{oDM}$)* and *324.54 L/(kg $_{oDM}$)* respectively at mesophilic temperature in batch experiments.
- It has been established that maize cob has the highest energy yields when compared to maize stalk and rice straw.

Acknowledgments

The first author is grateful to the Deutscher Akademischer Austauschdienst (DAAD), Germany for her financial support through the award of Research Scholarship for Doctoral Candidates on Sandwich Model to carry out this work at the Leibniz- Institute for Agricultural Engineering, Potsdam-Bornim, Germany.

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