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ENERGY PRODUCTIONS FROM SELECTED CROP RESIDUES THROUGH ANAEROBIC DIGESTION IN A FED-BATCH LABORATORY SCALE REACTOR AT MESOPHILIC TEMPERATURE

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ABSTRACT: *The present energy crisis has stimulated various research programmes to evaluate energy potentials of renewable energy sources. This work evaluated and compared the energy produced from anaerobic digestion of maize stalk (MS), maize cobs (MC) and rice straw (RS) by batch experiment at mesophilic temperature (37◦C). The study was carried out in a laboratory scale batch digester. The digestion bottles were fed with 9.95, 11.70 and 7.53 g, respectively, which were calculated. The digestion took place for a period of 34 days after which the gas production was noticed to be below 1% of the total gas produced till that time. The biogas yields from organic dry matter (oDM) of MS, MC and RS were found to be 357.10 l. kg^{-1} oDM, 514.31 l.kg^{-1} oDM and 324.54 l. kg^{-1} oDM respectively after 34 days digestion time. Methane yields (oDM) of MS, MC and RS were also found to be 222.39 l.CH_4 kg^{-1} oDM, 298.39 l.CH_4kg^{-1} oDM and 211.30 l.CH^4kg^{-1} oDM respectively. The biogas/methane yields from fresh mass (FM) of MS, MC and RS were found to be 147.59 l. kg^{-1} FM / 91.91 l. kg^{-1} FM, 180.65 l. kg^{-1} FM / 104.81 l. CH_4kg^{-1} FM and 177.29 l. kg^{-1} FM / 115.43 l. CH_4kg^{-1} FM. The equivalent energy of MS,MC and RS were found to be 9.35, 13.47 and 8.35 MJ respectively. Also, MS, MC and RS maize stalk were found to have methane concentrations of 61.9, 58.0 and 65.1%, respectively. This study has established that among MS, MC and RS, MC has the highest biogas and methane yieldsand in turn, energy potential*.

KEYWORDS: *Batch experiment, biogas potential, energy, maize cob, maize stalk, mesophilic temperature, rice straw*

INTRODUCTION

Anaerobic digestion (AD) is an environmentally sustainable technology for converting a variety of feedstocks (waste sources) including manure, the organic fraction of municipal solid waste (OFMSW), and agricultural residues to energy in the form of methane (Demirer *and Chens*, 2005). The gas produced through anaerobic digestion is called biogas which consists primarily of methane (CH_4) and carbon dioxide (CO_2), with varying amounts of water, hydrogen sulphide (H_2S), oxygen and other compounds (Madu & Sodeinde, 2001, Keefe & Chynowet, 2000, and Ten-Brummeler & Koster, 1990).

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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. 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 and manure had been used in the past in the production of biogas (Adebayo *et al.*, 2013, 2014a and 2014b). Jekayinfa and Scholz reported that there is availability of large amounts of non-plantation biomass resources in Nigeria for modern energy applications. According to Akinbami *et al.,* (2001), the energy consuming activities in the household sector which are cooking, lighting and operation of electrical appliances have consistently accounted for over half of Nigeria's total domestic energy consumption.

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.

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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:

$$\frac{oTS_{substrate}}{oTS_{seedingsludge}} \leq 0.5 \qquad (1)$$

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

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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 two times in a week 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).

Readings of the gas production (ml), air pressure (mbar), gas temperature (^oC) and time of the day were taken on daily basis throughout the period of the experiment. The gas was analysed with the use of the gas analyser GA 2000 model for at least twice per week for the four weeks of the experiments. The gas factor was calculated as well as the fresh mass biogas and methane yield with the volatile solid biogas and methane yields also determined on daily basis. The amount of gas formed was converted to standard conditions (273.15 K and 1013.25 mbar) and dry gas. The factor was calculated according to equation (3).

$$F = \frac{\left(p - P_{H_2O}\right).T_o}{(t + 273.15).p_o} \quad (3)$$

Where

T_o= 273.15 ^oC (Normal temperature)

t= Gas temperature in ^oC

P_o= 1013.25 mbar (standard pressure)

P= Air Pressure

The vapour pressure of water P_{H_2O} is dependent on the gas temperature and amounts to 23.4 mbar for 20^oC. The respective vapour pressure of water as a function of temperature for describing the range between 15 and 30^oC is given as in equation (4)

$$P_{H_2O} = y_o + a.e^{b.t} \quad (4)$$

Where:

y_o = -4.39605; a = 9.762 and b= 0.0521

The normalized amount of biogas volumes is given as

$$Biogas[N\,ml] = Biogas[ml] \times F \quad (5)$$

Normalized by the amount of biogas, the amount of gas taken off of the control batch is given as

$$Biogas[N\,ml] = \left(Biogas[Nml] - Control[Nml]\right) \quad (6)$$

The mass of biogas yield in standard liters / kg FM fresh mass (FM) is based on the weight

The following applies:

1 standard ml / g FM=1 standard liters / kg FM = 1 m^3 / t FM

$$Mass\,of\ biogas\ yield = \sum \frac{Biogas[N\,ml]}{Mass[g]} \quad (7)$$

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The oDM biogas yield is based on the percentage of volatile solids (VS) in substrate

$$oDM\ biogas\ yield\ = \sum \frac{Biogas[N\ ml).100]}{Mass[g].VS[\%FM]} \quad (8)$$

$$CH_{4corr.} = \frac{CH_4[vol\%].100}{(Mass[g]+CO_2[vol\%])} \quad (9)$$

$$Fresh\ Mass\ Methane\ yield\ = \frac{Fresh\ mass\ biogas\ yield \times CH_{4corr.}}{100} \quad (10)$$

$$oDM\ Methane\ yield\ = \frac{oDM\ biogas\ yield \times CH_{4corr.}}{100} \quad (11)$$

Plate 1: Size Reduction for effective fermentation


Plate 2: Batch Experimental set-up

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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*./(kg $_{oDM}$), 514.31 *l*./(kg $_{oDM}$) and 324.54 *l*./(kg $_{oDM}$) respectively after 34 days digestion time. Methane yields (oDM) of MS, MC and RS were also found to be 222.39 *l*.CH_4/(kg $_{oDM}$), 298.39 *l*. CH_4/(kg $_{oDM}$) and 211.30 *l*.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*./(kg $_{FM}$) / 91.91 *l*. CH_4/(kg $_{FM}$), 180.65 *l*. /(kg $_{FM}$) / 104.81 *l* .CH_4/(kg $_{FM}$) and 177.29 *l*. /(kg $_{FM}$) / 115.43 *l*. 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	-

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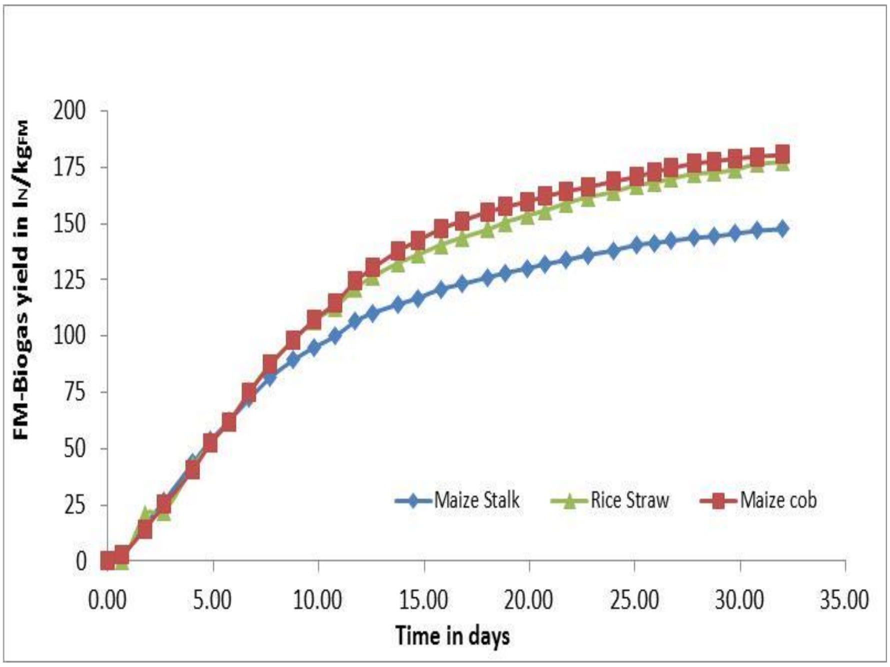

Figure 1: Daily Fresh-mass Biogas yield of MS, MC and RS as Substrates

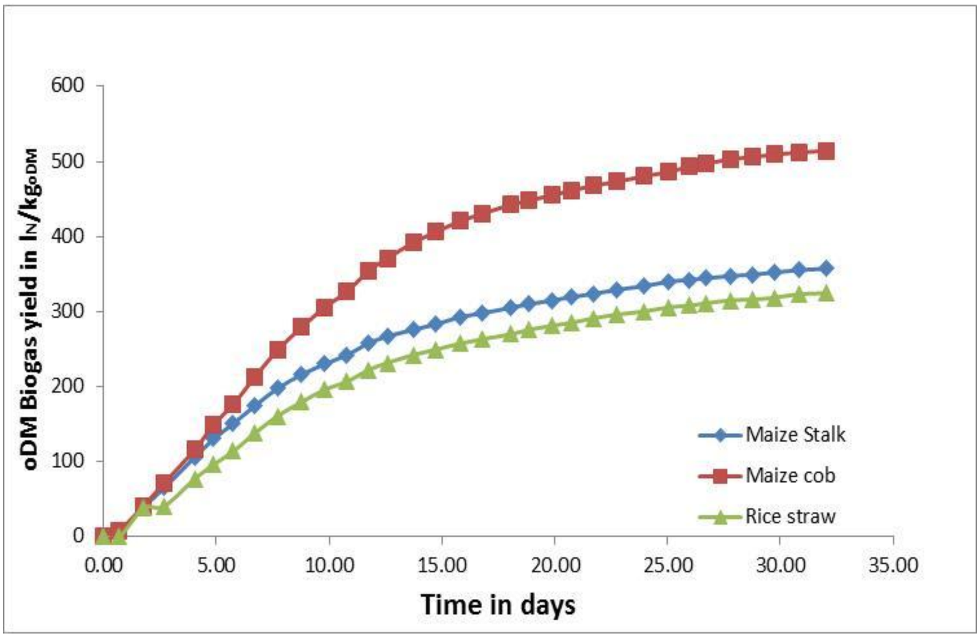

Figure 2: Daily oDM Biogas yield of MS, MC and RS

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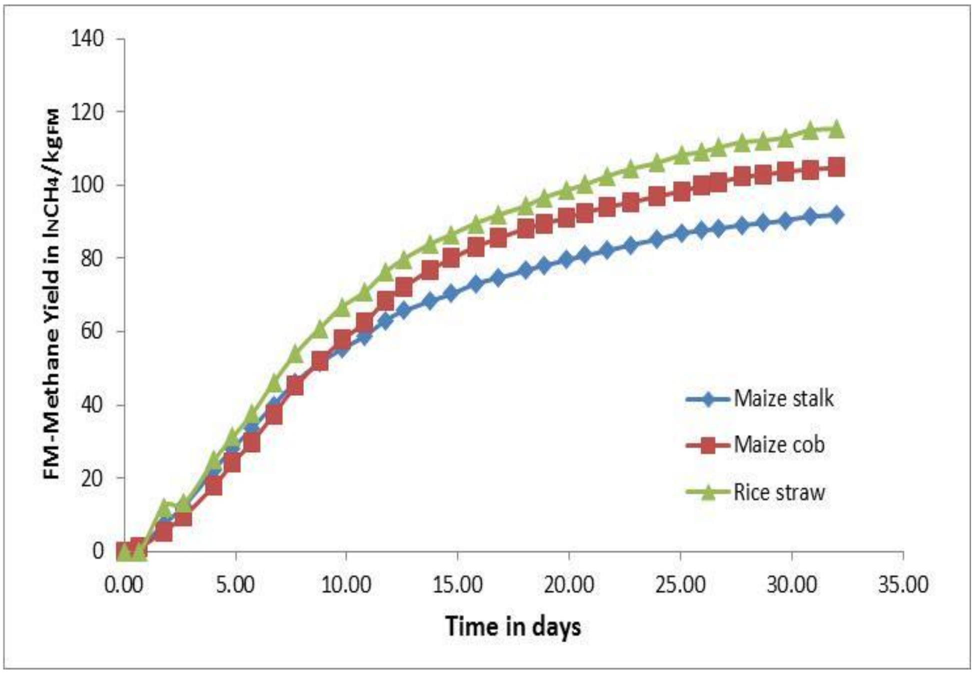

Figure 3: Daily Fresh-Mass Methane yields of MS, MC and RS

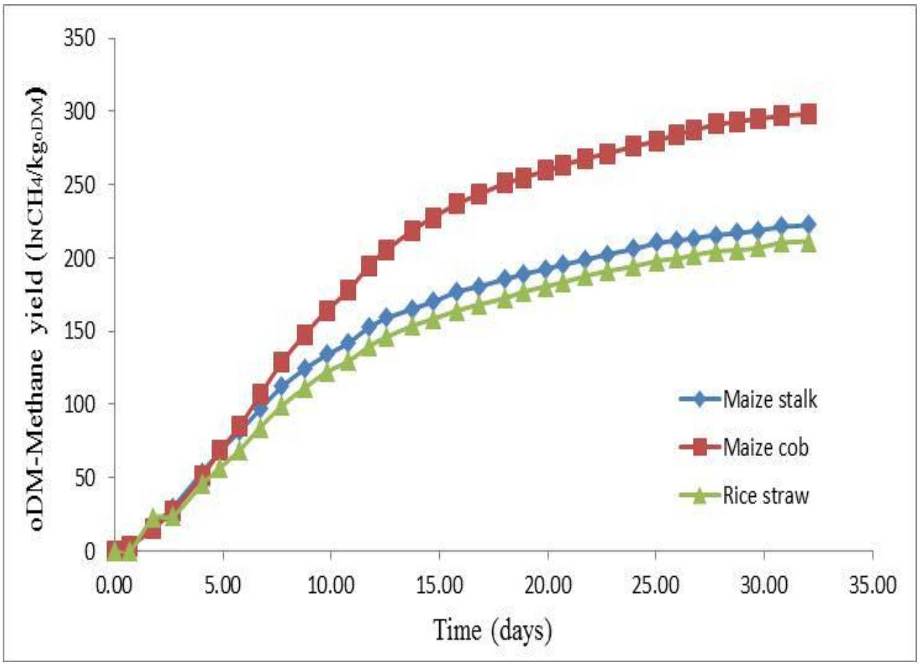

Figure 4: Daily oDM- Methane yields of MS, MC and, MS, MC and RS

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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

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 experiment.
- It has been established that maize cob has the highest energy yields when compared to maize stalk and rice straw.

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