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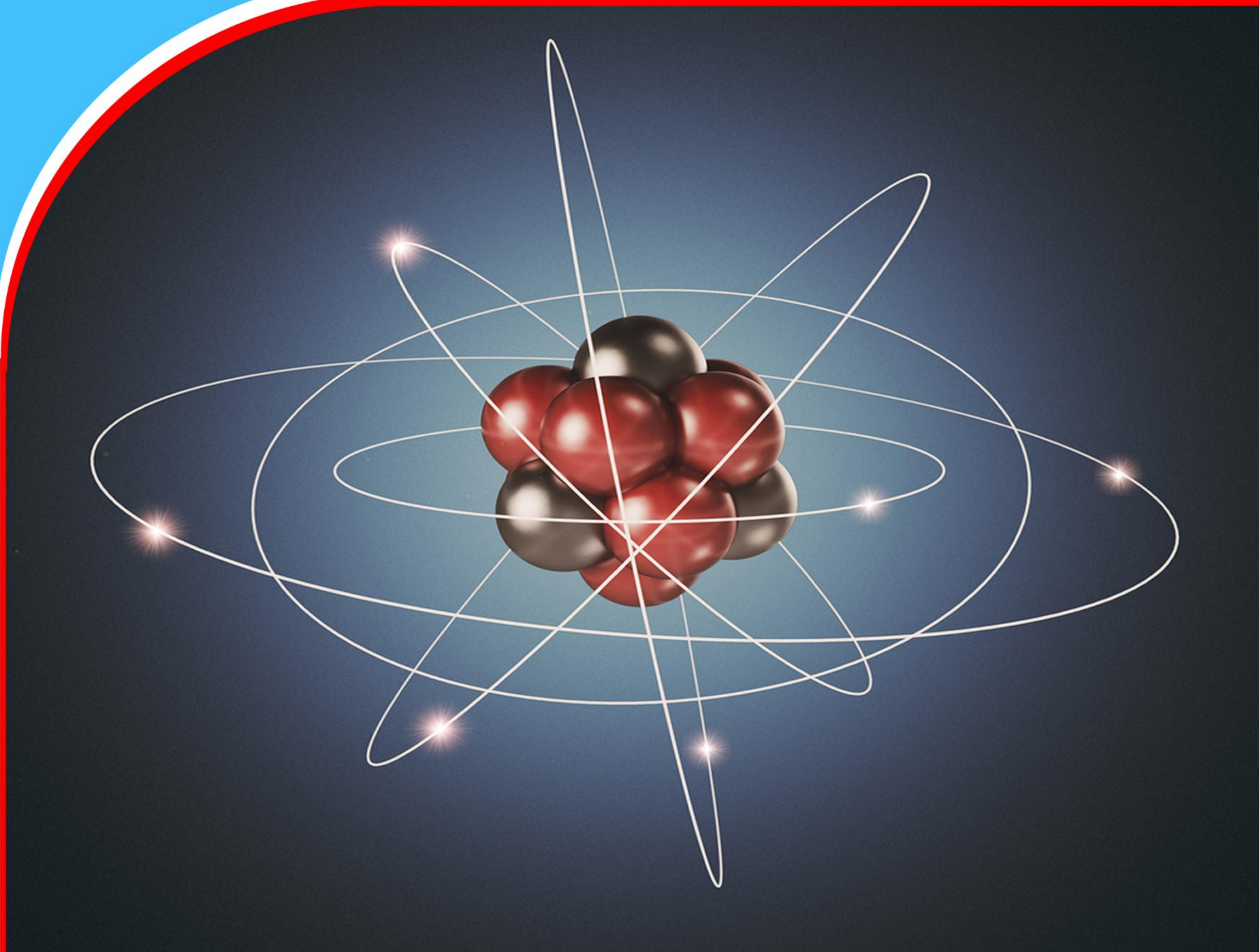

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EFFECTS OF CO-DIGESTION OF POULTRY DROPPINGS AND MAIZE COBS ON BIOGAS YIELDS AND SOME PROXIMATE PROPERTIES OF THEIR BY-PRODUCTS

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Abstract

Purpose: The study focused on Co-digestion trials of poultry droppings and maize cobs in order to assess its effects on biogas yield and some proximate properties of their by-products.

Methodology: Five different treatment ratios A(25:75), B(50:50), C(75:25), D(100:0) and E(0:100) of these wastes in triplicates were made into slurries (1:3w/v ratio) and separately fed to 13.6L locally fabricated digesters for 56 days retention time. There was a progressive increase in biogas yield across the treatments within the first six weeks of digestion, followed by a sharp decline at the 7th and 8th weeks.

Findings: All co-substrates treatments had higher gas yields in the order of B(2481.30ml) > D(2197.90ml) > A(2163.00ml) > C(2116.30) > E(1713.20ml). The proximate contents gave E(763.60%), A(153.73%), B132.44%), C(79.37%), D(48.06%) as % increases in ash, while %decreases in crude lipid and moisture contents were E (77.04, 21.02), B(72.70, 56.90), D(65.99, 40.94), A(65.70, 53.21) and C (56.83, 49.89), respectively. All but treatment D(5.74%) had % increases in crude protein. There was a general decrease in total solids(TS), volatile solids (VS), chemical oxygen demands (COD), metabolizable energy(ME). All co-substrates had higher % bioconversion efficiencies(%BE) over the singles with B(24.50%), C(57.90%) and A(21.39%) highest values for TS, VS and ME reduction, respectively. The % C/N reduction was in the order of treatment E(81.80%)> A(68.02%)> B(54.42%),>C(54.23%) >D (12.94%).

Unique contribution to theory, practice and policy: The process had revealed the alternative energy potentials and consequential implication on the biochemical composition of the effluents.

Keywords: *Co-Digestion, Biogas, Maize Cob, Poultry Droppings and Effluents*

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INTRODUCTION

Biogas is a renewable produced from biodegradation of energy crops, organic biomass, manures, sewage, municipal waste, green waste, and plant material. It occurs mostly under mesophilic (25°C-40°C) and thermophilic temperatures (45°C -60°C) but rarely psychrophilic (12°C-30°C) (Usman, Olanipekun & Ogunbanwo, 2012). The process continues naturally in swamps, spontaneously in landfills containing organic wastes and induced artificially in digestion tanks (digesters) for sludge, industrial and farm organic waste treatment (Igoni, Ayotamuno, Eze, Ogaji & Probert, 2008). The incorporation of a combination of two or more organic waste types into a treatment unit, have revealed an improved buffer capacity, high methane yield and stable performance(Umetsu *et al*.,2006). Co-digestion also provides an efficient way to significantly increase biogas production due to the changes of feedstock characteristics (Adelekan & Bamgboye, 2009). This corroborated the findings of (Callaghan, Wase, Thayanithy & Forster, 1999), who reported superior yield from co-digested slurries of cattle manure with fruit and vegetable wastes over the digestion of cattle slurry alone. Current study, therefore focused on effects of co-digestion of maize cob and poultry droppings on biogas yield and some proximate properties of their by-products.

MATERIALS AND METHODS

Substrate preparation

The locally sourced agricultural wastes (poultry droppings and maize cob), were air-dried, pulverized and subjected to pre-anaerobic digestion treatments, before mixing in five predetermined ratios (w/w) (table 1). They were aseptically parked into sterilized black polythene bags and stored in a cool dry place below 20^{o}C (Saev, Koumanova & Smeonov, 2009).

Table 1: Treatment description

Treatment	Description	Ratio
A	PD + MC	25:75
B	PD + MC	50:50
C	PD + MC	75:25
D	PD + MC	100:0
E	PD + MC	0:100

PD = poultry droppings, MC = maize cob

Slurry Preparation, Loading and Biogas Measurement

Different slurries were made by mixing 1000g of each of the treatment samples with sterile distilled water in a 1:3 ratio w/v, (Ojolo, Oke, Animasahun & Adesuyi,2007). These slurries were separately loaded in 13.6L capacity sterilized digesters with a thermometer and a gas delivery pipe fittings, and made airtight to ensure anaerobic condition. Triplicates of all such digester settings (making fifteen experimental units) were arranged in a completely randomized design (CRD) in an experimental cubical maintained under uniform temperature condition. The digesters were manually shaken once daily to ensure homogenous condition, and kept for a 56 day retention time. The method downward displacement of water was used to measure weekly biogas production (in dm3/kg), for eight weeks (Chomini, Ogbonna, Falemara & Thlama, 2014).

Proximate analysis of substrates and spent slurry

Separate fractions of the dried, pulverized samples (digested and undigested) (A to E) were subjected to standard methods (AOAC, 2005), to determine the following proximate compositions: moisture content (MC), crude protein (CP), crude fibre (CF), crude lipid (CL), nitrogen free extract (NFE), total ash (TA), total solid (TS) and volatile solid (VS), total nitrogen (TN) and total organic carbon (TOC). While Chemical oxygen demand (COD) was determined by the methods of (APHA, 2005).

Determination of Metabolizable Energy (ME) of the Experimental Substrates before Anaerobic Digestion

The determination of metabolizable energy (ME) of all the samples before and after anaerobic digestion, was carried by the methods of (Pauzenga, 1985) described by (Dairo & Egbeyemi, 2012). This was achieved by calculating the M.E. value for each of the samples, using the formula:-

$$M.E. = 37 \times \%\,CP + 81.8 \times \%\,EE + 35.5 \times \%\,NFE.$$

Where: % CP = Percentage crude protein (from proximate analysis)
% EE = Percentage ether ester (%lipid from proximate analysis)
% NFE = Percentage nitrogen free extract (from proximate analysis)

RESULTS AND DISCUSSION

Effects of Anaerobic Digestion on Biogas Production

The weekly results on mean biogas yield(ml) showed a general increase with retention time during the first six weeks, which decreased sharply at the 7th and 8th week. All the combined treatments recorded higher gas yields than the single substrates, with treatment B(50:50 poultry droppings : maize cob), recording the highest average value(512.0ml) while treatment E(0:100 poultry droppings : maize cob) had the least (348.70ml) at 6 weeks of digestion. There were significant differences ($p<0.05$) in weekly mean volume of biogas production throughout the

8weeks of the retention period (Table 2). The effects of co-digestion on cumulative biogas yield indicated 2481.30ml, 2197.90ml, 2163.00ml, 2116.30 and 1713.20ml for treatment B(50:50 poultry droppings : maize cob), D(100:0 poultry droppings : maize cob), A(25:75 poultry droppings: maize cob), C(75:25 poultry droppings: maize cob) and E(0:100 poultry droppings : maize cob) respectively (Figure 1).

The initial high level of biogas yield within the first 6 weeks of digestion was attributed to the presence of organic fraction and high microbial community in the substrates (Chomini, Ogbonna, Falemara & Micah, 2015). This was explained as an index of bioconversion of the organic biomass by (Kaosol & Sohgrathok, 2012), relating the gas production directly to metabolism of organic fraction of the digestate, stating that 1.0g of COD removal equals 395 ml methane. El-Mashad, and Zhang (2010), posited that biogas yield increases with COD removal, suggesting that the methanogenic consortium inured effectively, leading to organic matter digestion (COD and VS removal). The reduction in quantity of the biogas yield after an initial increase was explained by Xie, Lawlor, Frost, Hud and Zhan (2011), to be due to depletion of soluble biodegradable organic fraction, accumulation of volatile fatty acids and a low pH. Proteins are also known to influence methane formation positively and therefore a high methane yield can be attained from substrates rich in proteins (Amon *et al*, 2007).

The highest biogas yield obtained from treatment B(50:50 poultry droppings: maize cob) at the end of 56 days retention time corroborated findings of Lehtomaki, Huttunena, and Rintala (2007), who obtained an optimal yield from co-digested 1:1 ratio of cattle manure, grass silage, sugar beet tops and oat straw. The biogas yield was significantly ($p<0.05$) influenced by co digestion, as well as mixing ratio of the substrates. The cumulative average volume of biogas yield after 8 WOD was in the order of 50:50 (poultry droppings: maize cob) > 100:0(poultry droppings : maize cob) >25:75(poultry droppings : maize cob) >75:25 (poultry droppings : maize cob) > 0:100 (poultry droppings : maize cob)(Figure 1).

Effects of Anaerobic Digestion on Proximate Constituents of the By-Products

All treatments had percentage increases in ash (E(763.60%), A(153.73%), B132.44%), C(79.37%), D(48.06%), and %decreases in crude lipid and moisture contents (E (77.04, 21.02), B(72.70, 56.90), D(65.99, 40.94), A(65.70, 53.21) and C (56.83, 49.89), respectively after anaerobic digestion(AD). While all treatments showed a % increase in crude protein content, treatment D had a reduction of 5.74%. Conversely, only treatment D recorded an increase of 76.03% in crude fiber, while all other treatments showed various % decrease due to AD. However, treatments D and E gave % reduction of 18.05% and 18.12% in nitrogen free extract (NFE), while all the mixed substrates A, B and C had increments of 69.28%, 59.47% and 8.87% respectively(Table 3).

The 8 weeks of AD effected in a general reduction in total solids (TS), volatile solids (VS), chemical oxygen demand (COD), and metabolizable energy (ME) across the treatments. All co-substrates had higher percentage bioconversion efficiencies(%BE) over the single substrates for TS, VS and ME reduction, with treatments B(24.50%), C(57.90%) and A(21.39%) recording highest values respectively. Only treatments A and B gave superior %BE over the single substrates for COD reduction. Thus the optimal substrate mixing ratio for the substrates (poultry droppings: maize cob) for better bioconversion efficiencies (%BE) were ratios 50:50 (for TS and COD), 75:25 (for VS) and 25:75 (for ME). Thus, accounting for highest biogas yield from treatment B(Table 4).

Many workers (Tchobanoglous, Hilary, George, & Samuel, 1993; Eze & Okonkwo, 2013), indicated that high moisture contents usually facilitate the anaerobic digestion (AD), however, it is difficult to maintain the same availability of water throughout the digestion cycle (Hernandez-Berriel, L.M. Benavides, D.J.G. Perez, O.B. Delgado, 2008). High water content is likely to affect the process performance by dissolving readily degradable organic matter. It has been reported that the highest methane production rates occur at 60–80% of humidity (Bouallagui, Cheikh, Marouani & Hamd, 2003). Moisture content between 70 to 80% was found to initiate methanogenesis (Hernandez-Berriel). However, bioreactors under the 70% moisture regime had a stronger leachate and consequently a higher methane production rate.

The increase in crude protein content of all the substrates after AD suggested that their initial values were adequate for the process (Ofoefule & Ibeto, 2010). Adeyemi, & Familade (2003), attributed this to the release of nitrogenous and non–nitrogenous fractions in addition to microbial single cell protein, bioconversion of soluble carbohydrate fractions in the substrates to bacterial protein (Vijayan, Joseph & Raj, 2009), coupled with the production of different enzymes and biomolecules, which are proteinaceous (Nwanna, 2003).The reduction in crude lipid contents of all treatment effluents has been attributed to its metabolism during AD. As a high energy source, lipid metabolism into short chain fatty acids, releases ATP for microbial growth, accounting for lower terminal % lipid (Nwanna, 2003).

The reduction in percentage crude fibre content varied with treatment substrates, except for C. These results were attributed to the activities of cellulolytic microbes contained in the substrates, production of various enzymes during the vegetative and reproductive phases (Belewu, & Belewu, 2005). Akinfemi, Babayemi, (2009), opined that type of fungi species as well as the nature of the fibre were major determinants for crude fibre fraction reduction. The digestion of fibre fraction was connected to the soluble sugar production, which increases the energy content, part of which is utilized for biogas production, with the residual converted into microbial protein to boost the protein fractions of the resultant effluents (Adenipekun & Okunlade,2012). The process requires water for solubilization of the lignin fraction at the vegetative and reproductive phases thus, necessitating a decrease in moisture content.

The high proportion of total solid (TS), volatile solids(VS), chemical oxygen demand(COD) and total organic carbon(TOC) contents of influents depicts that a large fraction of the wastes is biodegradable and could serve as an important feedstock for biogas production (Jha, Zhang, Ban & Y. Jin, 2013). This is an indicative consumption by fermenting and methanogenic bacteria. The TS content of the wastes had been thought to be comprised of the ash and VS(biodegradable portion of the organic substrate). The degradation of the VS fraction would have resulted in a reduction of the TS of the spent slurries (Uzodinma & Ofoefule, 2009) found that VS of organic wastes decrease as anaerobes degrade them.

Jha *et al*.(2013), described the efficiency of the degradation process in terms of biological conversion of the substrates with VS or COD removal. This conversion implied reduction of organic waste simultaneously with production of biogas. Consequently, the differential between the initial and final values of TS, VS and COD reflects the level of removal, which is an index of the bioconversion efficiency (BE). This is reported to be directly proportional to the volume of biogas generated (Bagudo, Garba, Dangoggo & Hassan, 2008)[33]. Volatile solids and COD removal efficiencies of organic wastes can be enhanced under thermophilic condition than mesophilic temperature (Jha *et al*., 2013).

The variations observed of the values of the effluents on these parameters reflect the bioconversion efficiency. According to Umar, Firdausi, Sharifah and Fadimtu(2013), VS removal efficiency is a vital parameter for determining biodegradation which directly signifies the metabolic status of most delicate microbial groups within the anaerobic system. This consequently denotes the process stabilization.

Macias-Corral *et al*.(2008), explained that the highest initial values of %BE for TS, VS and COD removal for mixed treatment (co-digested) substrates indicated apparent synergistic effect which improve nutrient and boost biodegradation.

The bioconversion efficiencies equivalent to TS were in the order of treatment B(50:50 poultry droppings:maize cob)>C(75:25 poultry droppings:maize cob)>A(25:75 poultry droppings:maize cob)>D(100:0 poultry droppings:maize cob)>E(0:100 poultry droppings:maize cob)(Table 4). This is similar to observations by Blummel, Makkar and Becker (1997), who recorded highest volatile solids removal in 1:1 mixing ratio of pig manure blended with grass.

The initial higher metabolizable energy (ME) values of the substrates were considered adequate to effect reasonable biogas production (Ofoefule & Ibeto, 2010). This is used to power the preliminary processes (hydrolysis, acidogenesis and acetogenesis), which culminated in methanogenesis. According to Jha *et al*. (2013), considerable high energy input is required to maintain thermophilic temperature conditions for biological activities within the digesters. Schafer, Letho and Teye (2006), showed that initial low gas production was due to utilization of ATP (energy) for increased microbial growth. As levels of acetate production increased more gas is produced, which in turn results in lower ATP production (acetogenesis). This is consequent upon the utilization of more of the energy component (TS, VS, TOC, crude protein, and Lipid), accounting for lower terminal values and invariably, metabolizable energy reduction for all the treatments after digestion (Ghasimi, Idris, Chuah & Tey, 2009)(Table 4).

Effects of Anaerobic Digestion on Carbon –Nitrogen Ratio of Treatment Substrates

All treatments recorded significant reductions in C/N ratio, due to anaerobic digestion. The percentage C/N reduction indicated that treatment E(0:100 poultry dropping: maize cob) had 81.80% as the highest %reduction, followed by treatments A(25:75 poultry dropping: maize cob), B(50:50 poultry dropping: maize cob) and C(75:25 poultry dropping: maize cob) with 54.42%, 54.23% and 12.94% respectively, while treatment D gave least(12.94%)(Table 4).

The carbon-to-nitrogen ratio (C:N) obtained for the substrates before digestion was in line with Adenipekun and Okunlade(2012), stressing that an excessively high C:N ratio would increase the acidity of the medium which retards methanogenesis. Co-digestion provides supplementary and complementary nutrient requirements which trigger increase in digestion performance and methane yield, (Kacprzak, L. Krzystek, S. Ledakowicz., 2010). This is because the animal manure fraction of the co-substrate provides high buffer capacity, which mainly contains wide variety of nutrients necessary for optimal bacterial growth (Macias-Corral, et al., 2008). It also promotes synergistic effects, which overcomes the imbalance in nutrients resulting in higher mass conversion and lower weight and volume of digested waste thereby improving biodegradability.

In their views (Adelekan & Bamgboye, 2009), suggested that substrates with a very high C/N ratio produced very low biogas, but when co-digested with those of the lower C/N ratio, increased methanogenesis. Plant-based organic substrates are highly ligno-cellulosic, thus mixing with animal wastes would lower the C/N ratio of the mixture, enhance their digestibility, with more gas production. Mixing ratio affects biogas yield, irrespective of biomass waste type. Thus, mixing ratios meant higher C/N as well as lignin content, which represses microbial activities and methanogenesis (Adelekan & Bamgboye, 2009). When the C:N ratio is too low, nitrogen is converted to ammonium-N at a faster rate than it can be assimilated by the methanogens, leading to NH_3 poisoning. According to Kacprzak *et al*. (2010), an excessively high C:N ratio meant high acid formation which retards methanogenesis and biogas yield. This could have necessitated the pattern of yield for lower C:N treatments (D and E), despite their status as co-substrates. The 75:25 mixing ratio (treatment C) had the highest biogas yield, which is attributed to its relatively low lignin content, least C:N (Figure 2).

CONCLUSION

The study has revealed the biodegradative capacity of poultry droppings and maize cob to generate biogas at varying quantities. However, co-digested substrate ratio 50:50 had the optimal biogas production, while 0:100(poultry droppings:maize cob) had the least. The gas production is a function of and is affected by C/N ratio and bio-conversion efficiency of total solids, volatile solids and chemical oxygen demand removal, which engenders metabolizable energy change. The anaerobic digestion of poultry droppings and maize has also elucidated and enhanced some biochemical potentials of the wastes for industrial applications. Trials incorporating other organic substrates and mixing ratios should be performed in order to generate more useful results.

Table 2: Mean Gas Production (ml/wk) During Eight Weeks of Anaerobic Digestion

Tmt	Weeks							
	One	**Two**	**Three**	**Four**	**Five**	**Six**	**Seven**	**Eight**
A	62.0^{bc}	102.3^{b}	190.0^{b}	295.0^{c}	398.0^{d}	442.7^{c}	366.7^{b}	306.3^{c}
B	63.0^{c}	113.0^{d}	240.0^{c}	309.7^{d}	462.3^{e}	512.0^{e}	418.0^{d}	363.3^{e}
C	60.0^{b}	108.0^{c}	193.3^{b}	262.3^{a}	310.0^{a}	464.0^{d}	382.7^{c}	336.0^{d}
D	93.3^{d}	150.7^{e}	262.7^{d}	316.3^{e}	382.3^{c}	423.3^{b}	385.0^{c}	184.3^{a}
E	43.3^{a}	78.3^{a}	134.3^{a}	287.3^{b}	321.3^{b}	348.7^{a}	303.3^{a}	196.7^{b}
∑	321.6	552.3	1020.3	1470.6	1873.9	2190.7	1855.7	1386.6

Means along each column bearing different superscripts are significantly different ($P < 0.05$) at 5% level by Duncan's New Multiple Range Test; Tmt = Treatment

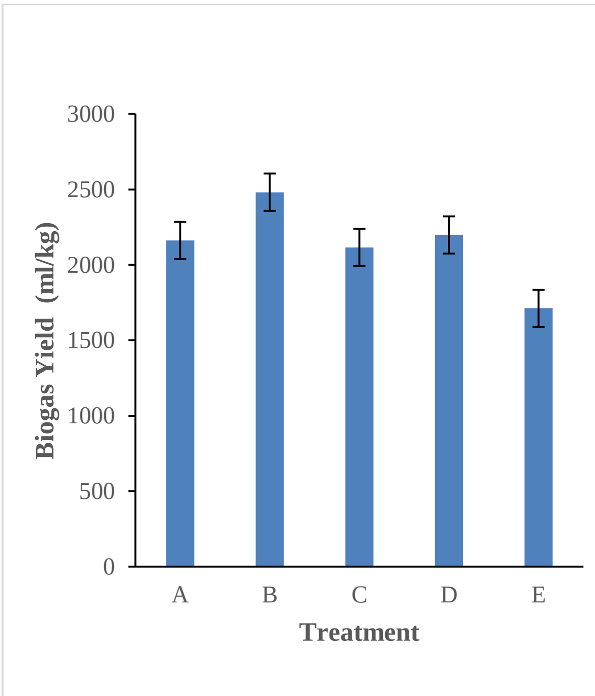

Figure 1: cumulative biogas yields after 8 weeks of digestion

Table 3: Effects of Anaerobic Digestion on Proximate Composition on Resultant Effluents

Tmt		AS	CL	CF	NFE	CP	MC
A	BAD	10.72	8.60	31.94	38.22	5.69	4.83
	AAD	27.20	2.95	5.08	64.70	17.81	26.26
	%diff	153.73	-65.70	-84.10	69.28	213.01	-53.21*
B	BAD	16.03	11.61	24.39	32.64	10.69	4.64
	AAD	37.26	3.17	7.91	52.05	17.61	28.00
	%diff	132.44	-72.70	-67.57	59.47	64.73	-56.90
C	BAD	23.70	8.20	19.92	29.86	13.75	4.57
	AAD	42.51	3.54	12.91	32.51	16.24	27.29
	%diff	79.37	-56.83	-35.19	8.87	18.11	-49.89
D	BAD	30.69	6.88	10.68	31.31	16.19	4.25
	AAD	45.44	2.34	18.80	25.66	15.26	15.51
	%diff	48.06	-65.99	76.03	-18.05	-5.74	-40.94
E	BAD	2.83	9.54	36.98	43.26	3.06	4.33
	AAD	24.44	2.19	22.66	35.42	11.87	10.42
	%diff	763.60	-77.04	-38.72	-18.12	287.91	-21.02

AS = % Total ash; CL = Crude Lipid; CF= Crude Fiber; NFE = Nitrogen Free Extract; CP = Crude Protein; MC= Moisture Content; BAD = Before Anaerobic Digestion; AAD = After Anaerobic Digestion; Tmt = Treatment.
* = negative (−) value equivalent to percentage reduction, due to anaerobic digestion.

Table 4: Effects of Anaerobic Digestion on %bioconversion efficiency of Effluents

Tmt		TS	VS	COD	ME	C/N Ratio
A	BAD	95.17	84.45	50.00	2601.91	43.49
	AAD	73.74	46.54	21.00	2045.38	13.91
	%BE	-22.52	-44.89	-58.00	-21.39	68.02
B	BAD	95.36	79.33	57.00	2357.46	23.52
	AAD	72.00	34.74	11.00	1996.77	10.72
	%BE	-24.50	-56.28	-80.70	-15.30	54.42
C	BAD	95.43	71.73	38.00	2386.20	19.73
	AAD	72.71	30.20	33.00	2082.34	9.03
	%BE	-23.81	-57.90	-13.16	-12.73	54.23
D	BAD	95.76	65.07	41.00	2233.57	14.30
	AAD	84.49	39.05	27.00	2104.03	12.45
	%BE	-11.77	-39.99	-34.15	-5.80	12.94
E	BAD	95.67	92.84	47.00	2533.72	108.14
	AAD	89.58	65.14	25.00	2089.74	19.68
	%BE	-6.37	-29.84	-46.81	-17.52	81.80

TS = Total Solids; VS = Volatile Solids; COD = Chemical Oxygen Demands; ME = Metabolizable Energy; C/N = C:N ratio; %BE = Percentage Bioconversion efficiency; BAD = Before Anaerobic Digestion; AAD = After Anaerobic Digestion; Tmt = Treatment; * = negative (−) value equivalent to percentage reduction, due to anaerobic digestion.

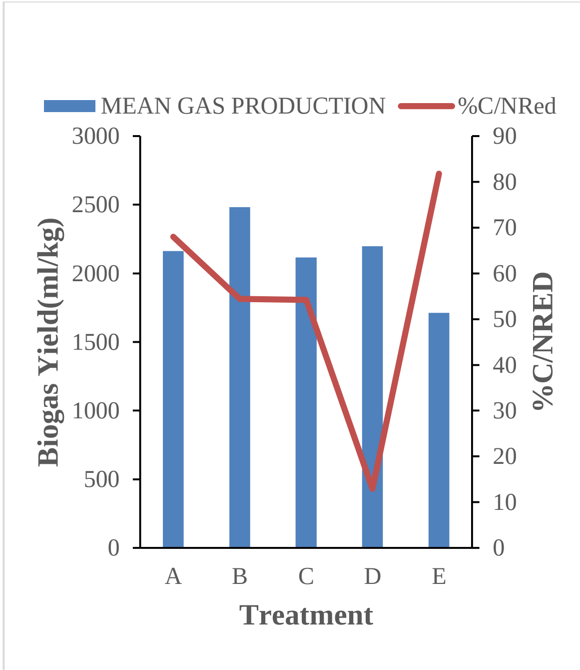

Figure 2: Biogas yield as it relates with C/N_{RED}

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