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Assessment of Anaerobic Co-Digestion Effects of Maize Cob and Poultry Manure on Biogas Yields and Their Digestate Characteristics

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Authors' contributions

Both authors collaborated in the execution of the study from the start to the finish.

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ABSTRACT

Aim: The aim of the study was to assess the effects of anaerobic co-digestion of maize cob and poultry manure on biogas yields and their digestate characteristics.
Place and Duration of Study: Department of Forestry Technology, Federal College of Forestry, Jos between March and April, 2018.
Methodology: Slurries of five co-substrate treatment ratios viz 0:1(T_1), 1:3(T_2), 1:1(T_3), 3:1(T_4) and 1:0(T_5) of these wastes (in three replicates) were separately fed to 13.6L locally made batch-digesters. The anaerobic reactors were monitored for a 56 day retention period. Weekly biogas yields and some digestate characteristics were measured by standard methods.
Results: The cumulative biogas yields was in the order of T_3(2481.3 mL/kg) >T_l(2197.9 mL/kg) > T_4(2163.0 mL/kg) > T_2(2116.3 mL/kg) >T_5(1713.2 mL/kg), in favor of the mixed substrates. While the percentage C:N reductions ranged from (12.94% - 81.80%), with T_5 and T_1 recording the highest and lowest values respectively. The chemical oxygen demand removal was in the order of T_3(80.70%) > T_4(58.00%) >T_5(46.81%) >T_1(34.15%) >T_2(13.16%). The anaerobic digestion (AD) effected reductions in Mg, C, Ca, P, Mn, Zn, Fe, Pb and increase in Cu contents of the digestates across treatments. While the K contents increased in T_2(36.72%), T_3(229.79%) and T_4(220.51%);

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%N in T_3(9.94%), T_4(113.19%) and T_5(291.84%) and Na increased only in T_4(4.55%). The Cu contents indicated % increase in the order of T_5(487.5%) >T_3(270.97%) >T_2(268.10%) >T_4(43.66%) >T_1(35.82%).
Conclusion: The anaerobic co-digestion of these organic wastes had unlocked the alternative energy potentials, enhanced the bioremediation tendency, while promoting sustainable public health and environmental management.

Keywords: Biogas; co-digestion; digestates; maize cob; poultry manure.

1. INTRODUCTION

Fossil fuels are non-environmentally friendly and unsustainable energy. The development of renewable bioenergy is an alternative solution to meet the electricity and heat requirements of the country with a cost-efficient and beneficial for the environment technology [1].

The European Landfill Directive (1999/31/EC) stated that by 2016, the disposal of biodegradable municipal wastes be reduced by 75%. Consequently, biological treatment of agricultural and bio-industrial wastes via the deployment of anaerobic digestion (AD) technology became imperative [1]. The technology not only produces clean renewable energy (biogas) suitable for heat and electricity production, it also generates a nutrient-rich digestate, used as bio-fertilizer [2]. The process of AD is valued for improved efficiency of the agricultural wastes management systems which is helpful in decreasing the emission rate of the greenhouse gases.

Other Benefits of the AD of animal manure include pathogen reduction under mesophilic or thermophilic conditions, odor and pests reduction [3]. The process also provide a bioremediating effects of heavy metals content of the digestates. Despite the efforts over the years, full exploitation of the organic wastes for bio-methanogenesis in Nigeria is still at its infancy [4]. This work focuses on the assessment of effects of anaerobic co-digestion of maize cobs and poultry manure on biogas yields and its implication on their digestate characteristics.

2. MATERIALS AND METHODS

2.1 Substrate Preparation

The bio-wastes sourced from the agricultural farms and research units of Federal College Forestry, Jos, Nigeria, were pretreated by drying, screened and pulverized, before purposively mixing in five selected ratios (w/w), parked in sterile black polythene bags and stored below 20°C until use [5]. The co-substrate mixtures of the wastes were described as follow:-

T_1 = 0:1 ratio comprised 0.0 g maize cob + 1000.0 g poultry manure
T_2 = 1:3 ratio comprised 250.0 g maize cob + 750.0 g poultry manure
T_3 = 1:1 ratio comprised 500.0 g maize cob + 500.0 g poultry manure
T_4 = 3:1 ratio comprised 750.0 g maize cob + 250.0 g poultry manure
T_5 =1:0 ratio comprised 1000.0 g maize cob + 0.0 g poultry manure

(where T_1,T_2, T_3, T_4 and T_5 represented treatments 1,2,3,4 and 5 respectively)

2.2 Anaerobic Digestion Trial

Each of these co-substrates was mixed with 3000 mL of distilled water in a 1:3 ratio (w/v). Three replicates of the resulting slurries were separately fed to the 13.6L digesters, with fittings of thermometer and gas delivery pipe, and firmly sealed to achieve anaerobic condition. The 15 reactor units were arranged in an experimental chamber, using a completely randomized design (CRD), maintained under uniform temperature. The digesters were manually jolted for one minute daily at a scheduled time, to achieve homogeneity. Weekly biogas yield (dm3/kg) was measured by downward displacement of water the gas [6], throughout the 8 weeks of digestion [7].

2.3 Analytical Methods

Separate fractions of the co-substrates before and after anaerobic digestion were subjected to Standard methods to determine the substrates biochemical characteristics. The chemical oxygen demand (COD) was determined, using Spectrophotometer DR 2800 [8]. Total N was determined by Kjedahl method. The nitrogen content in the sample was calculated using the formula given below.

$$\% \text{ nitrogen} = \frac{(a-b)\ x\ 0.01\ x 14\ x\ c}{d\ \ x\ \ e}$$

Where:- a = titre value for digested sample; b = Titre value for the blank; c = Volume to which the digest was madeup with distilled water; d= Aliquot distilled; e = Weight of dried sample.

The total organic carbon (TOC) was determined according to the standard procedure of [9]. The method of [8] was adopted to determine % P content, using the vanadate-molybdate reagent, at a wavelength of 470 nm, using the Atomic Absorption Spectrophotometer (AAS) (CTA-2000 AAS Chemtech Analytical). The P content was calculated using the following formula:-

$$P\ \frac{(mg)}{Kgsample} = \frac{(\text{GR x TCV x EV})}{\text{AVxW}}$$

Where: - GR = Graph reading; Tcv = Total coloured volume; Ev = Extract volume.
A_V = Aliquot volume taken.;W = Sample weight in gram.

The K, Ca, Na and Mg contents were determined by standard method [8], using the flame photometer, while Mg was determined using the atomic absorption spectrophotometer (AAS), based on the formula below:-

$$(\text{K, Ca, Na, Mg})\ \frac{(\text{K,Ca,Na,Mg})}{\text{Kg sample}} = \frac{\text{GR x EV x MCF}}{\text{39.1 x 10 x W}}$$

Where: - GR= graph reading (mg/L); mcf = moisture correction factor; Ev= Extract volume (mL); Av = Aliquot volume taken (mL); W = Sample weight (g); 39.1 = Equivalent weight of K; 10 = Conversion factor from ppm to cmol (+)/kg sample.

The Fe, Cu, Zn, Mn and Pb contents were determined by the [10] method, adopted by [11], using atomic absorption spectrophotometer (AAS).

3. RESULTS

3.1 Effects of Anaerobic Digestion of Samples on Biogas Yields, Chemical Oxygen Demand (COD) and Carbon-Nitrogen Ratio

There was a general increase in average biogas yield within the first six weeks of digestion (WOD), followed by a sharp decrease at the 7th and 8th week. T_5 (1:0:- maize cob + poultry manure) had the lowest biogas yields of 43.3±7.6, 78.3±6.5, 134.3±12.1, 348.7±20.8 and 303.3±6.1 at 1,2,3,6, and 7 WOD respectively. The cumulative biogas yields was in the order of T_3(2481.3 mL/kg) >T_I(2197.9 mL/kg) > T_4(2163.0 mL/kg) > T_2(2116.3 mL/kg) >T_5(1713.2 mL/kg) (Table 1). Analysis of variance (ANOVA) on weekly data indicated difference (P< 0.05) in average volume of biogas produced throughout the period of digestion due to substrate type and mixing ratio.

The anaerobic digestion has effected considerable reductions in chemical oxygen demand (COD(mg/L)) contents of substrates, with the co-substrate having higher percentage reduction, in the order of T_3(80.70%) > T_4(58.00%) >T_5(46.81%) >T_1(34.15%) >T_2(13.16%). Similarly, there were percentage reductions in C:N ratios across the treatments. However, the %reduction was in the order of T_5(81.80%) > T_4(68.02%) >T_3(54.42%) >T_2(54.23%) >T_1(12.94%) (Table 2).

The biogas yields were affected by the ratios of mixing of the co-substrates. The yields followed the order: 1:1 >0:1 >3:1 >1:3 >1:0. This revealed mixed substrates with higher maize cob (C-content) and or low poultry manure (N-rich) gave higher % reduction of C/N ratio.

3.2 Effects of Anaerobic Digestion on Mineral Element and Heavy Metal Compositions of Digestates

There were variations in the mineral and heavy metal composition of the digestates due to anaerobic digestion (AD). Before AD, the contents of Mg ranged from 793.00 to 2002.20 mg/kg, OC(37.03-52.99%), Na(0.08-0.26%), Ca(450.50-16234.00 mg/kg), P(1608.75-15843.75 mg/kg), but reduced to 0.39-1.17 mg/kg; 17.52-37.78%; 0.06-0.14%; 0.07-3.96 mg/kg and 0.096-0.982 mg/kg respectively. The contents of K increased in T_2(36.72%), T_3(229.79%) and T_4(220.51%); %N in T_3(9.94%), T_4(113.19%) and T_5(291.84%). Na increased only in T_4(4.55%) (Fig. 3). After AD, all treatments had % reductions in heavy metals (Mn, Zn, Fe and Pb), except Cu, which indicated % increase in the order of T_5(487.5%) > T_3(270.97%) > T_2(268.10%) > T_4(43.66%) > T_1(35.82%) (Fig. 4).

Table 1. Mean biogas production (mL/wk) during eight weeks of anaerobic digestion

Treatments/Weeks	1	2	3	4	5	6	7	8	Total
T_I	93.3±4.2^{d}	150.7±19.0^{c}	262.7±16.6^{d}	316.3±15.0^{d}	382.3±12.5^{c}	423.3±14.0^{b}	385.0±7.0^{c}	184.3±12.1^{b}	2197.9
T_2	60.0±9.2^{b}	108.0±15.1^{b}	193.3±14.0^{b}	262.3±11.2^{a}	310.0±5.0^{a}	464.0±20.3^{d}	382.7±5.0^{c}	336.0±8.5^{d}	2116.3
T_3	63.0±4.2^{c}	113.0±8.2^{b}	240.0±12.0^{c}	309.7±4.0^{d}	462.3±12.5^{d}	512.0±5.3^{e}	418.0±5.3^{d}	363.3±13.3^{e}	2481.3
T_4	62.0±15.1^{c}	102.3±12.5^{b}	190.0±13.1^{b}	295.0±11.8^{c}	398.0±5.3^{c}	442.7±5.0^{c}	366.7±6.1^{b}	306.3±8.5^{c}	2163.0
T_5	43.3±7.6^{a}	78.3±6.5^{a}	134.3±12.1^{a}	287.3±15.7^{b}	321.3±8.1^{b}	348.7±20.8^{a}	303.3±6.1^{a}	196.7±16.7^{a}	1713.2
$\sum$	**321.60**	**552.30**	**1020.30**	**1470.60**	**1873.90**	**2190.70**	**1855.70**	**1386.60**	**10671.70**

Means along each column bearing different superscripts are significantly different ($P < 0.05$) at 5% level by Duncan's New Multiple Range Test; T_1 = 0:1 :- 0.0 g maize cob + 1000.0 g poultry manure; T_2 = 1:3 :- 250.0 g maize cob + 7500.0 g poultry manure; T_3 = 1:1 :- 500.0 g maize cob + 500.0 g poultry manure; T_4 = 3:1 :- 750.0 g maize cob + 250.0 g poultry manure; T_5 =1:0 :- 1000.0 g maize cob + 0.0 g poultry manure (where T_1,T_2, T_3, T_4 and T_5 represented treatments 1,2,3,4 and 5 respectively)

Table 2. Chemical Oxygen Demand (COD) ($x10^3$ mg/L) and Carbon-Nitrogen (C/N) ratio of substrates before and after anaerobic digestion

Tmt	COD_{BAD}	COD_{AAD}	CODR(%)	C/N_{BAD}	C/N_{AAD}	$\%C/N_{Red}$
T_1	41	27	34.15	14.30	12.45	12.94
T_2	38	33	13.16	19.73	9.03	54.42
T_3	57	11	80.70	23.52	10.72	54.42
T_4	50	21	58.00	43.49	13.91	68.02
T_5	47	25	46.81	108.14	19.68	81.80

T_1 (0:1:- 0.0 g maize cob + 1000.0 g poultry manure); T_2 (1:3:- 250.0 g maize cob + 7500.0 g poultry manure); T_3(1:1:- 500.0 g maize cob + 500.0 g poultry manure); T_4(3:1:- 750.0 g maize cob + 250.0 g poultry manure); T_5 (1:0 :- 1000.0 g maize cob + 0.0 g poultry manure) (where T_1,T_2, T_3, T_4 and T_5 represented treatments 1,2,3,4 and 5 respectively)

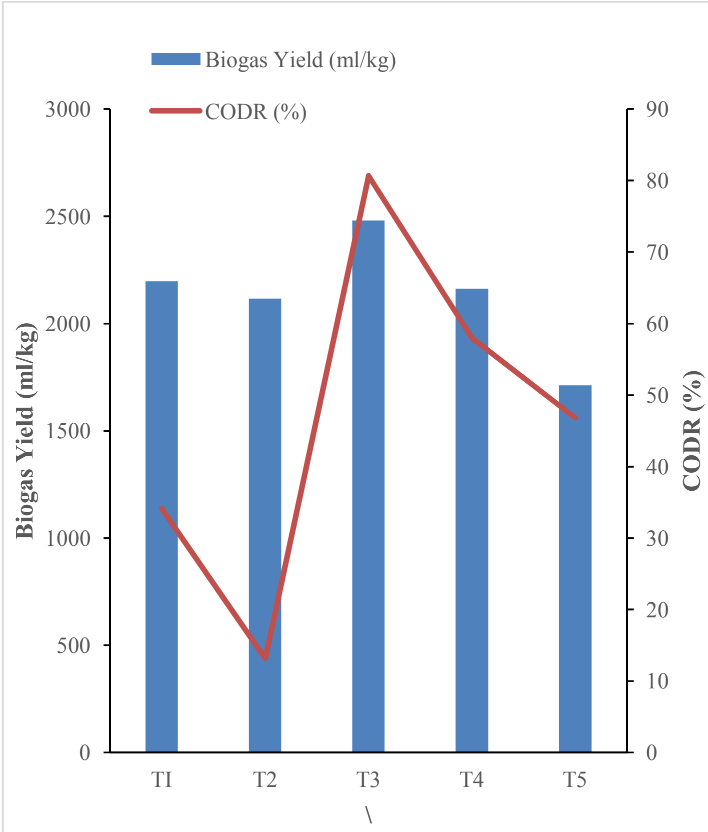

Fig. 1. Effects of anaerobic digestion on biogas yields and COD$_{reduction}$
T_1 (0:1 : 0.0 g maize cob + 1000.0 g poultry manure); T_2 (1:3 : 250.0 g maize cob + 7500.0 g poultry manure); T_3(1:1 : 500.0 g maize cob + 500.0 g poultry manure); T_4(3:1 : 750.0 g maize cob + 250.0 g poultry manure); T_5 (1:0 : 1000.0 g maize cob + 0.0 g poultry manure) (where T_1,T_2, T_3, T_4 and T_5 represented treatments 1,2,3,4 and 5, respectively)

4. DISCUSSION

The increase in biogas yields during the first six weeks of anaerobic could be attributed to high biodegradable fractions of organic wastes and high load of microbial communities of the slurries, corroborating findings of [12], who maintained that high presence of organic matter and microorganism communities in the medium affects biogas yields. The observed sharp reduction in gas volume after an initial increase, strengthens the inclination of [13], to lack or reduction of soluble biodegradable fractions of the substrates, accumulation of volatile fatty acids (VFAs) and a low pH. Before digestion, all substrates had higher values of % chemical oxygen demand %COD, which became reduced after the process (Table 2). According to [14], close relationship between biogas yield and COD removal exist, which proportionately increased with COD removal [15], as observed in this study (Fig. 1). This suggests that the methanogenic consortium acclimated very well, consequently leading to the digestion of organic matter (COD) and volatile solid (VS).

The highest cumulative biogas yield recorded by treatment T_3 (1:1:- maize cob:poultry manure) after 8 week of digestion was in line with the position of [16], indicating that co-digestate of ratio 1:1 of cattle manure blended with some plant residues gave an optimal yields. The yield was (P<0.05) influenced by co-digestion as well as substrate ratios. This result is similar to those of [17], accounting that substrate ratio 1:1 of livestock wastes blended with cassava peels gave an increase average biogas yield. They maintained that substrates with very high C/N ratio, produced very low biogas (Fig. 2). However, when co-digested with materials of lower C/N ratio, enhanced methanogenesis was observed, due to stabilized ratio at optimal range between 22 and 30 [18]. Co-digestion has been thought to enhance buffering capacity, microbial diversity, positive synergisms, more balanced and complementary nutrients supply [12]. Blending phyto-biomass with livestock wastes was found to lowers the C/N ratio of the blend, enhance digestibility, due to high microbial community. Mixing ratio affects yields as higher mixing ratios meant higher C/N as well as lignin content which could hinder microbial activities and methanogenesis [17].

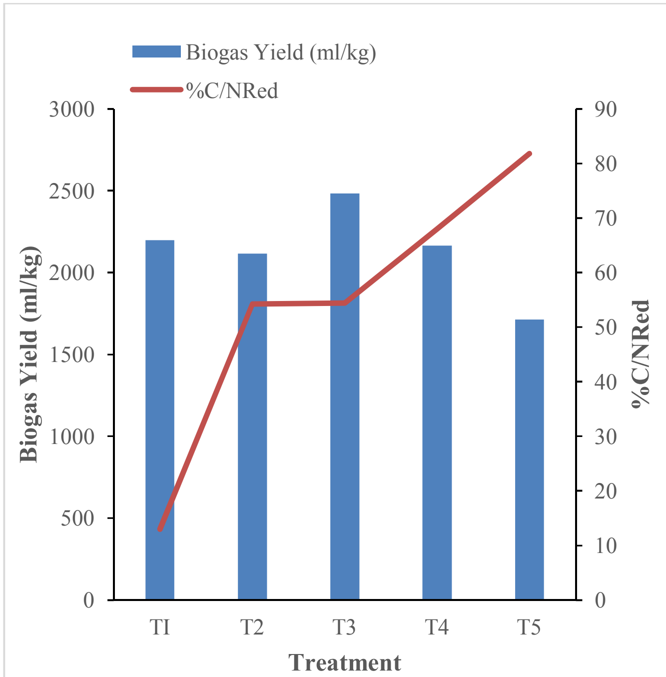

Fig. 2. Effects of anaerobic digestion on Biogas and C:N $_{\text{Reduction}}$

T_1 (0:1:- 0.0 g maize cob + 1000.0 g poultry manure); T_2 (1:3:- 250.0 g maize cob + 7500.0 g poultry manure); T_3(1:1:- 500.0 g maize cob + 500.0 g poultry manure); T_4(3:1:- 750.0 g maize cob + 250.0 g poultry manure); T_5 (1:0 :- 1000.0 g maize cob + 0.0 g poultry manure) (where T_1,T_2, T_3, T_4 and T_5 represented treatments 1,2,3,4 and 5, respectively)

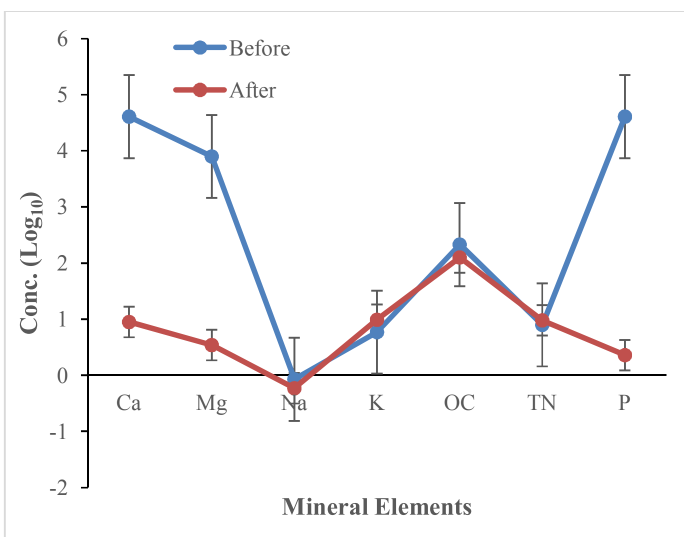

Fig. 3. Mineral element composition of substrates before and after anaerobic digestion

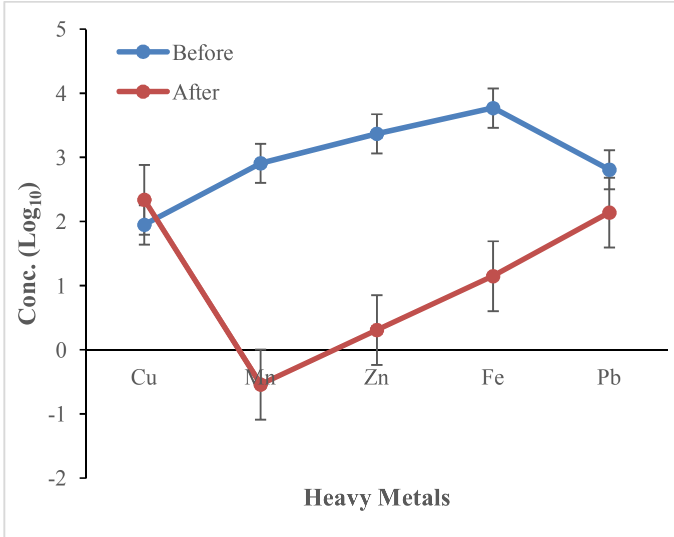

Fig. 4. Heavy metal composition of substrates before and after anaerobic digestion

High C:N ratio implied increased acidification and retarded methanogenesis [19], consequently, the yield pattern of T_5 with 81.80% $C/N_{Reduction}$ The C/N ratio obtained for the substrates before digestion were in line with [19], stressing that a high C:N ratio would increase acidity of the medium which retards methanogenesis. When the C:N ratio is too low, N is converted to ammonium-N at a faster rate than it can be assimilated by the methanogens, leading to NH_3 toxicity. Co-digestion provides supplementary and complementary nutrient requirements which trigger increase in digestion performance and methane yield, [20]. This is because animal manure fraction of co-substrate provides high buffer capacity which contains wide variety of nutrients necessary for optimal bacterial growth [21]. 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.

Based on their findings [22], reported a higher values of C, N, K, P, Zn, Cu, Mn, Na, and Pb in undigested poultry manure, which corroborated the current findings except for higher values for Cu. [23], opined that besides C, H, O needs, N, S, P, Ca, Mg and a number of micronutrients required for methanogenesis are predominantly found in most organic wastes. The reduction in Ca, Mg, Fe, Zn, Mn and Pb contents after anaerobic digestion (AD) was viewed as their utilization by degrading microbes to power the process [19], the extent of which determined their residual in the digestates. [24], claimed that Mg^{2+} enhances bio-remediating tendency of certain methanogenic strains by reducing K^+ toxicity during anaerobic digestion. It shows synergistic effects, when combined with Ca and Na at certain levels, helping the anaerobic process to recover from K inhibition [25]. Trace level of heavy metals during anaerobic biodegradation of organic matter is essential for the proper enzyme functioning, which could be inhibitory at high concentrations [26]. Heavy metals are only toxic to anaerobic bacteria in their soluble form. Microorganisms exposed to heavy metals consequently activate a wide variety of intracellular detoxification defense strategies. The reduction of heavy metals such as Fe, Zn, Pb, Mn but Cu assayed, in the present study revealed the bio-remediating tendency of the process. [27], attributed the reduction in concentration of Ca, Mg, Fe, Zn, Mn and Pb after digestion to the bio-remediating tendencies of microbial consortium present in the substrates. This involves mechanisms of metal binding to microbial biomass in the form of intracellular accumulation, sorption or complex formation on cell surface and extracellular accumulation or precipitation [28]. Manganese is required by microbes for the formation of Mnperoxidase, an enzyme which aids in the Lignin and lingo-cellulosic degradation [29]. The variation in contents of Na, K, Ca, Mg, and increase in N corroborated the findings of [30], pointing out that the buffering properties of the co-substrates favor the degrading microbes.

Microbial community under co-digestion could experience selective inhibition by heavy metal due to different tolerant levels leading to microbial community structure and functional stratification [31]. Thus, disrupt some microbial pathways, making them more sensitive to some metals than others, resulting in selective inhibition and decline in numbers and diversity of microbes relying on those pathways [32]. [33], related heavy metal removal to reductions in the COD removal with increasing metal concentrations. Also, [34] reported Cu toxicity on COD removal which recorded higher levels in the absence of Cu ions for all hydraulic residence time levels (HRTs) tested. [35], reported factors such as pH, metal concentrations before treatment, quantity biomass, temperature, retention time, presence of other ions could affect the reduction of heavy metal in digestive medium.

5. CONCLUSION AND RECOMMENDATIONS

The biodegradative capacity of maize cob and poultry manure mixtures to produce biogas at five ratios was assessed. Co-substrates especially ratio 1:1(T_3) yielded 2481.3mL/kg as the highest biogas, while 1:0(T_5) had the least (1713.2 ml/kg). The C/N ratio and COD removals proportionately affected gas yield. Higher volumes of biogas are produced at relatively higher C/N ratio higher COD removal. The anaerobic digestion of these organic wastes has enhanced the heavy metal reduction, thus elucidating the bioremediating tendency. However, further studies involving other agricultural and industrial organic wastes should be undertaken under varying controlled conditions for process optimization.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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